A QUANTITATIVE ANALYSIS OF THE SPEED OF DUTCH AND BRITISH SHIPPING, 1730-1850

A Thesis

by

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ABSTRACT

The period 1730-1850 brought no major revolution in the design of wooden ships. Yet the origins of naval architecture and the beginnings of scientific understanding of hydrostatics and hydrodynamics can be traced to this time. Accordingly, scholars have debated whether this period saw any significant improvements in the quality of ship designs. This study examines changes in length, tonnage, day's run, and speed-length ratio for British and Dutch ships built during the years 1730-1830 (British) and 1750-1850 (Dutch) through regression analysis. Data for this study is taken from the Climatological Database of the World's Oceans (CLIWOC), which contains the daily entries from thousands of logbooks for voyages 1750-1850.

British naval vessels gain in size and speed, but only 3rd rate vessels gain in speed-length ratio. This shows significant improvement in ship design, but suggests that speed under sail was not a primary objective of naval shipwrights. Length and tonnage were not available for Dutch naval vessels, but speed shows a significant, quadratic gain. The quadratic factor is likely due to the Netherlands taking a belligerent rather than neutral role in the later wars, which required the construction of larger vessels. British naval vessels are faster on average than Dutch naval vessels, but also probably larger on average. No national difference is found in the speed of frigates.

Length does not increase for British merchant ships (largely East India Company (EIC)), but tonnage, speed, and speed-length ratio do. Dutch merchant vessels prior to 1800 (largely Dutch East India Company (VOC), with a few vessels from the West

Indies Company, Middleburg Commercial Company, and private traders), show no increase in size or speed. After 1800, Dutch merchant ships’ speed increases until it matches that of British merchants. The VOC heavily regulated ship dimensions, and the data shows that this effectively suppressed improvements in Dutch ship design. Where standardization was absent, substantial gains in size and speed were achieved.

DEDICATION

This thesis is dedicated to Scott Baptista. I don't know how we got so lucky.

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NOMENCLATURE

EIC	East India Company (British)
VOC	*Vereenigde Oostindische Compagnie* (Dutch East India Company)
WIC	*West-Indische Compagnie* (Dutch West Indies Company)
MCC	*Middelburgsche Commercie Compagnie* (Middleburg Commercial Company)
Day's Run	The number of nautical miles a ship travels in a 24 hour period, measured from noon to noon
Average Day's Run	The average of all day's runs recorded for a given ship
Best Day's Run	The highest day's run recorded for a given ship
Speed-Length Ratio	The speed of a ship, measured in knots, divided by the square root of the vessel's length
Average Speed-Length Ratio	The speed-length ratio calculated using the average day's run divided by 24 as the speed in knots
Maximum Speed-Length Ratio	The speed-length ratio calculated using the best day's run divided by 24 as the speed in knots

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CHAPTER I

INTRODUCTION AND HISTORICAL BACKGROUND

Speed was a feature sought in sailing ships throughout history; Chapelle (1967, 3) states that "in all forms of transportation, an increase in speed of movement has been sought and has been accepted as a fundamental indication of progress." For merchant ships, shorter voyages reduced the amount of time in which capital was tied up in the cargo, the risk of goods perishing, and the costs of wages and insurance (French 1987; Rönnbäck 2012). It also meant less cargo space had to be devoted to carrying supplies for the crew, since they had to be sustained for shorter periods. Arriving earlier to markets could also give merchants a significant advantage over their competitors, especially for goods like tobacco that arrived in large quantities at the same time, glutting the market (Middleton 1946, 199). Speed also decreased the risk from pirates or enemy ships. For naval ships, it could mean the difference between capturing a prize or not; or between getting captured themselves or escaping. For ships that carried messages or chased pirates, speed was particularly important, and smaller vessels were built for speed to compensate for their smaller armament (Chapelle 1967, 3-5).

For shipbuilders, however, speed was just one of many factors to consider when designing a vessel, and improvements in any one area often negatively impacted the ship's performance in other areas (Nowacki 2006, 4-6). Increasing the armament might require a fuller body below water, for example, negatively impacting speed, while increasing the size of the rig might negatively affect stability or seaworthiness. Shipbuilders in different periods and places prioritized different factors. The reputations of French naval shipbuilders in the 18th century, as well as that of their ships, were judged by performance during initial fair-weather sea trials, so they built long and light ships that performed well in these conditions (Rodger 2003, 9-10). The contemporary British navy, on the other hand, was more concerned with keeping as many ships as possible at sea in different seasons, and their shipbuilders built heavily timbered ships with large holds capable of carrying stores for prolonged voyages (Rodger 2009, 14). Dutch shipbuilders had to build ships capable of navigating the notoriously shallow harbors of the Netherlands' coast, and their designs were accordingly constrained by this factor. Thus, even when shipbuilders sought to improve the speed of their vessels, they had to balance this objective against other factors.

In addition, the forces of hydrodynamics and propulsion that affect ship speed are incredibly complicated, and were poorly understood during this time period (Chapelle 1967, 22). It was not uncommon for the minor changes in hull form made during refits to significantly affect the performance of the vessel, and an accurate understanding of the reasons for the change was often lost (see, for example, the significant reduction in performance noted in the captured *Invincible* after the British Royal Navy refit the vessel in 1754-1756 (Lavery 1988, 64-67, 74-75)). Although attempts at scientific approaches to ship design date at least as early the 17th century, it was not until well into the 19th century that any truly usable theories were available to shipbuilders. Nonetheless, the long experience of shipbuilders, combined with the transfer of knowledge between countries, achieved improvements in theoretical and practical knowledge, and thus ship design. Historical studies indicate that both firepower and sailing performance improved throughout the 17th and 18th centuries (Unger 1997; Nowacki 2006, 47-48).

This thesis seeks to quantify the analysis of ship speed using data from the Climatological Database for the World's Oceans (CLIWOC), which contains the noon entries of more than 1600 historical logbooks dating from 1750 to 1850. It is a wealth of information on weather conditions, routes taken, ship speeds, and notable events on board, and even contains a fair amount of information on the ships that recorded them (Können and Koek 2005, 119). Although the database also includes a small sample of Spanish and French ships, this analysis will focus only on the Dutch and British ships, as there is more information provided for these ships.

Historical Background

In 1750, control of the world's oceans and the riches that overseas trade brought were highly contested. Two main theaters existed: the eastern trade with India and China and the transatlantic trade with the Americas. Both were highly valuable, bringing in raw materials, exotic manufactured goods, and crops that could not be grown in Europe, as well as providing markets for European manufactured goods. Controlling and protecting those markets was crucial, and depended in large part on control of the ocean routes that carried shipping.

The British transatlantic trade supplied a North American market that seemed insatiable. The population of the North American colonies exceeded one million people by 1750, and it doubled over the next decade (Bureau of the Census 1909). That growth fueled trade. In 1740, the British colonies were annually importing goods worth £100,000 more than the value of their exports; by 1760, their imports were worth nearly

£2 million more (Lemon 2001, 142). By volume, half of all colonial exports consisted of tobacco from the mid-Atlantic colonies and sugar from the West Indies. The West Indies imported much of their food from the mainland colonies and Ireland, as the majority of their arable land was given over to sugar plantations (Davis 2012, 258). Many of those who made their fortune from West Indies sugar plantations aimed to return with it to England, limiting the demand for high-end goods in the West Indies. In contrast, in the mainland colonies' stable and fast growing settlements demanded British-manufactured and luxury goods in increasing quantities (Davis 2012, 263).

The British government had a high stake in protecting that trade. The Navigation Acts (which constrained colonial trade to British ships) were originally passed to ensure sufficient numbers of ships and sailors for impressment in wartime, but by the 18th century were used as a form of trade protectionism (Davis 1966, 312; Sawers 1992, 267). During wartime, risks of capture skyrocketed, and the navy provided two measures of protection: cruisers along the coasts and in the approaches to the English Channel, and escorts for convoys. The former provided limited protection, as the cruising warships could not be everywhere, and there were never enough ships available to guarantee safety. The latter offered significantly more protection, but came at the cost of delays in waiting for the convoy to gather and for the escorts to arrive, and of the market being flooded by large volumes of goods coming into port at one time (Davis 2012, 316).

While the British demanded a monopoly on trade to its American colonies, trade to eastern and southern Asia was originally largely the province of the Dutch. Although the English East India Company (EIC, established in 1600) predated the *Vereenigde Oost-*

Indische Compagnie (Dutch East India Company, VOC) by two years, the VOC dominated trade to the east for nearly a century and a half. The VOC had begun with nearly ten times the financial backing than the EIC, a financial advantage it sustained for some time, sending on average seven ships for every three that the EIC did (Furber 1976, 38, 78). In addition, the VOC built its own ships while the EIC leased its vessels, which meant the VOC paid less for both the ship itself and any delays in time spent overseas (Barrow 2017, 52). The VOC's primary import was spices, and it artificially controlled their price by buying up excesses and holding them in warehouses, and even burning large quantities when needed. Early on, the Dutch established a single point of control in the east at Batavia, through which they dominated trade to and from the Spice Islands, the only place where cloves, nutmeg, and mace could be grown, effectively establishing a monopoly on these products (Barrow 2017, 18-20; Irwin 1991). The Dutch were less successful in controlling pepper, as it grew readily in many places (Barrow 2017, 18-20). Initially, the Dutch also carefully guarded their knowledge of routes, safe harbors, and weather patterns to keep their rivals out. However, the EIC established its own body of knowledge, and by 1747 printed charts of good accuracy were readily available for purchase throughout Europe (Mörzer Bruyns 1992, 146).

By the mid-eighteenth century, the French and especially the British were pushing into Asian markets once exclusively under Dutch control (Parry 1955, 206). During the 18th century, textiles (especially Indian cotton), coffee, and tea surpassed spices as the most important trade good. Although the VOC participated in the trade for these goods, the *Compagnie Française des Indes* (French East India Company, CFI) and especially the EIC did a far better job of taking advantage of the changes in Europe's market (Nierstrasz 2012, 2). Together, the EIC and VOC exported 22% of South India's cotton. The EIC alone imported an average of three yards of cloth per person in Great Britain from 1670 to 1760, although some of this was then exported to the Americas (Riello 2013, 113, 322-323). By the 1730's, Dutch profits were falling rapidly (down from 4 million in the 1720's to 1.3 million guilders) even though the total value of their trade continued to climb (Furber 1976, 40; Korte 1984, 60-61, Table 26).

The Dutch also began to lose their advantage in the country trade[1] to Britain and other powers during this time. The Dutch had once funded the entirety of their home trade with the profits from the country trade, especially from selling textiles in the Spice Islands. These networks of inter-Asian trade proved critical to the maintenance of successful trade relations for the home trade, and the Dutch loss cost them (Furber 1976, 40-46). Trouble at home did not help the Dutch. In 1745, the French seized the southern Staats Vlaanderen (States Flanders, a dependent territory of the Dutch Republic), sparking panic. What historian Jonathan Israel calls "the Second Orangist Revolution" (1747-1751) swept the country, and the Republic of Regents was replaced with a more authoritarian government under the Stadholder, a sort of "constitutional monarchy without a crowned monarch" (Israel 1998, 1077-1078). Although the border with France was neutralized with the Franco-Austrian treaty of Versailles (1756), unrest continued.

[1] The "country trade" was the local trade between ports within the Indian Ocean, such as between India

As the VOC control began to falter, British power in the east was expanding rapidly. Rather than establish a single center of control in the east, as the VOC had done, they had established several “presidencies.” In the mid-eighteenth century, Bengal was the most profitable of them, supplying more than 50% of all exports from Asia, including textiles, saltpeter, and indigo (Chaudhuri 2006, 509-510). To Europeans, the province appeared to be extremely wealthy, supporting an extravagant life for its elite class through land tax revenues. Officials in the EIC, facing criticism at home for exporting silver bullion (which was then considered the source of a country’s wealth), began to entertain a vision of funding the country trade with land tax revenues. The EIC charter, originally granted in 1660 and expanded periodically after, gave them the right “to make Peace or War with any Prince or People, that are not Christians, in any Places of their Trade, as shall be most for the Advantage and Benefit of The said Governor and Company, and of their Trade” (Charters granted to the East-India Company, 1772). The outbreak of the Seven Years War in 1756 granted them an opportunity to put that vision in place.

Seven Years War (1756-1763) and its Aftermath

The Seven Years War began as a territory dispute between Prussia and Austria in 1756, but evolved to include an extended overseas conflict between Great Britain (allied with Prussia) and France (allied with Austria) for control of North America. The Dutch Republic chose to remain neutral despite being by treaty defensive allies with England, as they still felt betrayed by the English withdrawal of troops during the War of Austrian Succession that had left their territory open to French attack (Carter 1963, 819-820).

The conflict would ultimately establish Britain as the strongest naval power of the world.

At the start of the war, the number of both ships of the line and frigates in the British fleet already exceeded that of France's fleet. They held several other advantages: more and better-equipped shipyards, greater control of naval stores, and a larger pool of experienced sailors and officers to man the ships (Kennedy 1983, 99-100). Still, the start of war meant launching a campaign of rapid ship construction. The haste with which new ships were needed exhausted the supply of seasoned wood in naval stores. The use of unseasoned wood, while sufficient for the conflict at hand, would later leave the navy unprepared to handle the American colonies' declaration of independence in 1776 (Kennedy 1983, 109-110).

The interests of the EIC were significantly advanced by the war, as the colonial contest soon spilled over into India. The EIC's holdings in the east provided the Royal Navy with secure bases, local stores, and storehouses; their ships served as a local navy, military transports, and source of seamen; and the Bombay dockyard provided access to skilled shipwrights and dry docks for repairs. So critical would dry docks prove to naval operations in the Indian ocean that a second one, large enough to hold a 74-gun vessel, was built in 1762 (Lambert 2002, 137-140). In June of 1756, the Nawab of Bengal, Suraj ud-Daula, alarmed by British preparations at Fort William in Kolkata, ordered the British to cease those preparations and to withdraw from Bengal territory. When they refused, he seized control of the fort. Shortly afterward, an account began to circulate how he imprisoned of 146 of the former residents of the fort in an eighteen-by-eighteen foot cell in Blackhole prison. It was said that due to the oppressive heat, press of people, and lack of food or water, only twenty-three emerged alive the next day (Holwell 1757).

Although historians doubt how accurate the sensationalist account was, at the time it inflamed public sentiment against the nawab. Under the direction of Lieutenant-Colonel Robert Clive, the recently appointed EIC Governor of Fort St. David, British forces moved against ud-Daula, defeating him by the following June. Clive installed a puppet nawab, Mir Jafar, thus effectively taking control over the trade and governance of Bengal, then the wealthiest of the Mughal provinces (Lawson 2014, 89-90). This move marked the start of the EIC's transition from a trading company to an imperial administration. Both the EIC and the British government had high hopes for how much money would be acquired through the *diwani*, or right to collect the revenue of a province, that they had been granted over Bengal (Barrow 2017).

Meanwhile the British navy was achieving remarkable success against the French. Although the war started poorly for them, the tide turned in 1759, later dubbed the *annus mirabilis*, or 'year of wonders.' Admiral Edward Hawke achieved a compete blockade of all of the entrances to Brest. This objective had long been considered impossible—blockading ships could be kept at sea for only four to five months before needing repairs, illness often set in among the men within just six weeks, and the size of the area that needed to be patrolled to maintain an effective blockade was staggering. Hawke succeeded by increasing the size of the Western Squadron until he could establish a system of rotation, systematically sending the vessels under his command to Torbay for cleaning, re-provisioning, and relieving their crews. In 1760 the blockade was continuously maintained for eight months, excluding only the winter months when military and naval actions were limited. By 1762, the blockade had been extended to Bellisle and Rochefort (Middleton 1989, 353, 259-363). This served to effectively protect England from invasion and to cripple French shipping.

The Dutch Republic traded freely with both sides. Philosophically, the role of the neutral power was understood at the time to mean not prolonging the war at the expense of one side or the other (Vattel 1758, Ch. 7, para. 110).[2] Both France and England contested in turns the appropriate role of the Dutch as a neutral party. One such contested area was the transport of timber from the Baltic, critical for the construction and maintenance of naval vessels. England carried out this trade on its own behalf but France largely relied on Dutch merchants for its supply (Carter 1963, 820-822, 825).

The Marine Treaty of 1674 between England and the Dutch Republic guaranteed Dutch merchants the right as neutrals to "not be in any ways hindered or molested in their Navigation or Trade" by English ships and laid out certain exemptions to contraband declarations, including naval stores (A treaty marine, 1674, Art. I). By the eighteenth century, however, England felt the Dutch trade in naval stores was not a neutral act as it would prolong the war by extending France's ability to contest England's control of the oceans. Lord Chancellor Hardwick went so far as to argue that by allowing the French to import timber in ships the English were obliged to not capture, the Dutch would be of more use to the French as neutrals than as allies (Hardwicke 1756).[2] The British accordingly seized a fair number of Dutch ships engaged in this

[2] Discussed in Carter (1963, 825)

trade, although they made little dent on the overall quantity of this shipping during the war (Carter 1963, 822).

Overall, shipping, far from being curtailed by the war, thrived. British shipping rose from 32,000 tons to well over 500,000 tons. By the end of the war, a third of all of Europe's merchant fleet were sailing under the British flag (Kennedy 1983, 105). The EIC accounted for fourteen percent of all imports into Britain during the eighteenth century (Barrow 2017, xxiii). Taxes from trade did much to support the extensive cost of naval wars, and provided a strong motivation for the British government to employ the navy to protect trade (Lambert 2002, 137; Syrett 1976, 169). Shipping costs did increase during war, due to increased insurance rates and the need to offer high wages to merchant seamen. The practice of impressment by the navy drove wages up by both limiting the supply of qualified seamen available to merchant shipping and because merchant seamen ran the highest risk of being impressed (Davis 2012, 313). Convoys were the main strategy for protecting trade, and they significantly reduced losses. In 1757, for example, the insurance premium for the transatlantic route from England to Virginia was 5 percent for ships sailing with the annual tobacco convoy and 10 to 12 percent for those sailing without (Middleton 1946, 194).

The EIC's finances deteriorated markedly after the war, and groups back home began to take a greater interest in the company's affairs. The company continued their policy of leasing ships built specifically for the trade with Asia. Since the Shipping Committee in charge of procuring ships awarded the contracts to their own shipyards, this generally resulting in ships that were unnecessarily expensive and ornate (Fichter

2010, 174-175). Worse, Bengal was not as wealthy a province as the opulent courts of the *nawab* had suggested, and the EIC's horrific crisis mismanagement impoverished the area. In 1769, the monsoon rains failed to come. By 1770, a severe famine had set in. The EIC did little to relieve the suffering. Local officials urged a remittance on the land tax, which was raised through the sale of agricultural products, but EIC officials refused. In fact, they collected more revenue in 1770 than they had the previous year, and then voted to increase the tax by a further 10% for the next year. Smallpox followed hard on the heels of the famine. It is estimated that a fifth to a third of the population of the province died of starvation or disease. In the end, the EIC never received even half of the four million pounds annually that had been projected, and the cost of maintaining an army to collect taxes was far higher than expected. By the 1770s, the EIC was in serious financial trouble (Barrow 2017, 53-61).

The British government stepped in. The first of the reforms came with the Regulating Act of 1773, aimed at stabilizing the heavily criticized electoral system. The act established a rotating system where only a quarter of the directors were up for election each year, rather than all of them. This reduced the focus of directors on the elections and granted increased continuity to governance. The act also largely eliminated the widespread practice of stockholders splitting their stocks among temporary holders who would cast votes in favor of measures or campaigns the original stockholder supported. This effectively consolidated control of the company into the hands of the thirty largest stockholders. Increased attention would continue to be focused on the Company's affairs as it moved into the role of administering territory on behalf of the

British government (Barrow 2017, 51; Bowen 2005, 60, 74-75).

The Dutch-owned VOC was in worse straits. Short-term loans taken out through 1736 turned into long-term loans as the balance of trade from Asia failed to repay the debts (Nierstrasz 2012, 2-3). During the late 17th century, the VOC relied on trading cloth for spices in order to reduce the amount of specie exported to Asia. Towards the end of the eighteenth century, the successful importation of spice plants into French and British colonies ended the artificial control of spice prices by the VOC and drove prices down (Parry 1955, 206). Simultaneously, the VOC found itself faced with the rising cost of cloth due to increased demand as the French and British companies moved into the market. Seeking to curb its debts and deficits, the VOC made the choice to step back from involvement with inter-Asian trade, halving their investment in it between 1750 and 1790, from 45 million guilders in 1761 to 28 million guilders in 1779 (Furber 1976, 178; Nierstrasz 2012, 2-3).

The Dutch also maintained small holdings in the Caribbean and South America and played an active, if small, role in the Atlantic slave trade. The *West-Indische Compagnie* (West Indies Company, WIC) was originally granted a monopoly on this trade in 1621 and established ports in West Africa to purchase slaves for the Dutch West Indies and Surinam. The monopoly lasted until 1730, after which the company took on a more administrative role. Overall, the Dutch Atlantic trade was modest. One estimate puts the annual number of all Dutch ships sent to the Atlantic colonies at around 200, eighty of which were slave ships (Emmer 2001, 42). The Dutch slave trade reached its peak in the early 1770s, before a recession in 1773 caused a significant decline. The outbreak of war two years later would halt the trade for several years (Postma 1990, 284).

American Revolutionary War (1775-1783), the Fourth Anglo-Dutch War (1780-1784), and their Aftermath

The rebellion of thirteen of the American colonies caught Britain off guard. The Navigation Acts had been laxly enforced since the 1720s, and the tightening of enforcement in 1764 following the Seven Years War bred resentment in the colonies. The acts sought to limit trade between Great Britain and its colonies to British citizens, required trade from Europe to be routed through England, and protected certain British markets, especially naval stores and manufactured goods (Sawers 1992). The rebellious colonies contributed a substantial portion of that trade—at the outbreak of the American Revolutionary War, their shipping was estimated as two parts in five of British trade with the West Indies and one part in three of England's total merchant shipping (Champion 1784, 17-19). A decade of growing tension between North American merchant interests and their mother country dissolved into war in 1775, with a formal Declaration of Independence following in 1776.

Concerns over the threat American privateers posed to British shipping led the navy to establish both patrols and convoys. In 1776, thirty-four ships-of-the-line were mobilized to patrol Channel waters for American cruisers, but they captured only fifteen over the next two years. Convoys were much more effective, and between 1776 and 1777, orders were given to establish convoy systems for trade with the Caribbean, North America, and the Baltic states; for East India Company shipping operating in the

Atlantic; and even for coastal trade and trade among ports in Great Britain and Ireland. By the end of 1777, virtually all British shipping had the option of sailing with a convoy (Syrett 1976, 170-172).

Because of the extent of trade with the colonies, the war affected British trade in a way that the Seven Years War had not. Bristol, for example, saw the annual volume of incoming shipping from the rebellious colonies fall 41.9 percent, from an average of 21,202 tons in 1773-1777 to just 12,326 tons in 1778-1780, although trade from Canada and the Caribbean did not dip (Morgan 1992, 633). Schumpeter (1960, 15-16) finds an overall dip in volume of British overseas trade during the war.

The French joined the war in 1778 on the side of the new United States of America, and Spain entered in 1779. The British, despite the success of the blockade against France in the previous conflict, did not pursue control of the Western Approaches. Fighting a war on the other side of the Atlantic was already proving a great strain on national resources. Simply ferrying 70,000 troops across the Atlantic with all of their supplies required 1,500 ships at a cost between £500,000 and £1,000,000 per year (Ryden 2001, 358; Hope 1990, 235-236). With the entry of the French, the Royal Navy found itself with four theaters to cover—the Channel, Gibraltar, the West Indies, and India—and insufficient strength to dominate in all of them (Kennedy 1983, 109). Within the Admiralty, further concerns were raised over the dangers of keeping ships at a station off the Western Approaches with its volatile weather (Saxby 1992, 26). Furthermore, France, in this war, unlike previous conflicts, did not have to divide its attention between a naval campaign and a Continental threat to its own sovereignty. It was thus able to match and sometimes exceed the size of the British fleets. By contrast, Great Britain's resources were divided between a naval war and an extended land war with the American colonies (Kennedy 1983, 110-112).

Without the key strategies of blockade and Continental diversion, France was able to mount serious threats to British holdings in both the West and East Indies, as well as to trade in both the Atlantic and Indian oceans. The British failure to intercept convoys of ships-of-the-line and troopships carrying soldiers and supplies cost them dearly in the West Indies (Dull 2015, 187-189). The Franco-Spanish capture of an entire convoy of five East Indiamen and forty-seven vessels bound for the West Indies in 1780 sparked panic at Lloyd's and a nine pound jump in freight charges to Asia, to £47.04 per ton (Sutton 2010, 137-138).

France was also able mount a significant threat against British holdings in India (Saxby 1992, 26). The EIC-owned Bombay dockyard proved to be "the key to sustained British dominance in Eastern seas," as it provided a strategic location for the navy to operate from, a secure and sheltered anchorage, a local shipbuilding industry with skilled labor, and, of especially key importance, the only dry docks in the region (Lambert 2002, 138-139). Secure access to teak was necessary to maintain this advantage, and a campaign was mounted against the ruler of Mysore, Tipu Sultan, for access to the forests of Malabar and Coorg. The British defeated him at Seringapatam in 1799 (Lambert 2002, 139). Trade protection during the war was handled by Bombay's local navy, the Bombay Marine, allowing the Royal Navy squadron to focus on enemy fleets (Lambert 2002, 139).

France's entry into the war also increased British tensions with the Dutch, who traded freely with the French. Although the Dutch right to neutral trade was guaranteed by the Anglo-Dutch treaty of 1674, the British began seizing Dutch ships caught trading with the French in 1778 (Scott 1988, 573). Tensions sparked war. The Fourth Anglo-Dutch War began in 1780 and lasted until 1784. It was a decisive victory for the British, gaining them territory in India and the West Indies as well as the right to trade freely with parts of the Dutch East Indies (Crout 1983).

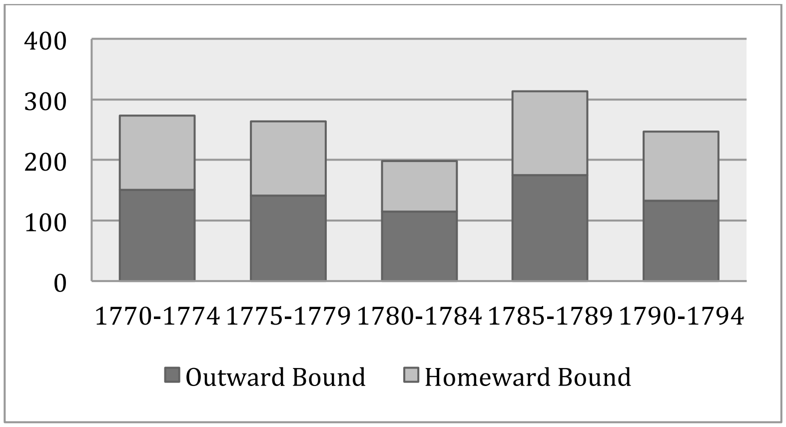
Concerns that the loss of the American colonies, then the largest market for British manufactured goods, would bring the empire to ruin proved unfounded. Britain was beginning to industrialize, and this brought substantial market gains. Between 1783 and 1792 the value of British exports to Europe doubled, creating a trade surplus of nearly £2 million. The new United States remained the largest market for manufactured goods, returning to pre-war levels by 1785. Despite the fact that by the early 1770s, one-third of the British merchant fleet had been built on America's eastern seaboard, British-owned shipping continued to increase after the war, reaching 1.5 million tons in 1792, up from 600,000 tons in 1760 (Evans 1996, 41-43). Cotton mills in Britain imported substantial quantities of raw materials from the United States.

Dutch trade was heavily affected during the period of hostilities. The Dutch navy was unable to provide significant protection to the country's large merchant marine, and losses to capture were high. In the Atlantic slave trade, for example, only a single Dutch slave ship was outfitted in 1781; it was captured the following year on the Africa coast. No Dutch ships carried slaves to the West Indies in 1783, and the Dutch colonies purchased slaves from foreign slavers. (When the war ended this trade would resume.) The role of the Dutch West Indies in providing supplies to the United States drew the attention of the British, who occupied both Dutch-owned Guyana and Surinam during the war (Postma 1990, 284-285, 288-289).

By the late 1770s, the VOC was not earning its dividends and had to borrow money to pay them out. Even before war broke out with Britain, the VOC's payments to shareholders were suspended (Furber 1976, 360). The Asian markets it relied on were growing in instability, fueled by political unrest and challenges to European power in the area (Nierstrasz 2012, 2-4). Although trade was not halted during the war, as some authors suggest (Nierstrasz 2012, 1), it was curtailed by the hostilities—Bruijn et al. (1979) show 198 voyages during the years between 1780 and 1784, down significantly compared to the five year periods before and after (Figure 1). The VOC earned no net profit after the war's end in 1784, and its monopoly on even the most profitable trade goods eroded away (Furber 1976, 360; Nierstrasz 2012, 212).

The Fourth Anglo-Dutch War and the steady faltering of the VOC were taken as further evidence supporting a narrative of national decline that had taken hold in the minds of the Dutch public (Callister 2017, 45). This spilled over into political unrest. The Patriot movement (1780-1787) and the Orangist Counter Revolution (1787-1795) pitted supporters of the Regents against those of the House of Orange (Israel 1998, 1088; Scott 1988, 577).

Figure 1 Number of VOC voyages during five-year periods from 1770 to 1794. The Fourth Anglo-Dutch War curtailed but did not halt Dutch trade during the period from 1780-1784. Data from Bruijn et al. (1979).



The British government, meanwhile, continued to take an interest in the affairs of the struggling EIC. In January of 1784, Pitt introduced the India Bill, saying India should be "the source of infinite benefit to the empire at large" (Frost 1980, 81-83). It established a Board of Control comprised of appointed ministers. It also limited the stockholders' ability to officially influence the Company's policies, although they could and still did bring pressure to bear on the directors. The act limited the Company's jurisdiction to commercial decisions, requiring the directors to secure formal approval from the Board for instructions and policies related to civil, military, or revenue policies in India (Bowen 2005, 75-77; Sutton 2010, 9).

The trade with China for tea and porcelain had long been growing. Before the American Revolutionary War, British tea imports reached 9 million pounds per two-year trading season. During the war they dropped to 6 million. The Commutation Act, passed in 1784, reduced the duties on foreign tea, making smuggling tea into Britain less profitable. Legal importation surged, returning to 9 million pounds in 1784-1785. The following season saw that climb to 14 million (Furber 1976, 175-176). By the end of the century, Britain would be importing 23 million pounds of tea from each trading season, and the EIC saw profits of £800-900,000 from its China trade, quadruple those of the mid 1770's. The value of the China trade increased in tandem with the Indo-British country trade, stabilizing and strengthening the EIC's position in the East (Furber 1976, 175-176).

Chief among the products exported from India to China to help finance the purchase of tea was opium. Although this trade was illegal in China until 1858, an active trade in the drug had long been carried out. The EIC entered it in 1708, quickly matching the quantity carried by their Dutch and French rivals. The British conquest of Bengal during the Seven Years War granted the EIC full control of the opium produced there. In 1772, they declared a state monopoly on the production and sale of opium. Within a couple years, abuses of power by the EIC officers holding the contracts for the processing and sale of opium led the EIC Governor-General Warren Hastings, to declare the revenue from opium as excise or tax funds rather than revenue on the private accounts of the company. Eventually the company took over the production and sale entirely (Richards 1981, 61-64). EIC produced opium was shipped from Calcutta to Canton by private traders, where it was smuggled ashore alongside missionaries anxious to convert the Chinese population to Christianity (Miller and Stanczak 2009, 333).

Coalition Wars: French Revolutionary Wars (1793-1802) and Napoleonic Wars (1803-1815)

The French Revolution soon sparked another global war between Great Britain and France, which would last from 1793 until 1802 (French Revolutionary Wars) and resume just one year later with the Napoleonic Wars (1803-1815). This series of conflicts is also called the Coalition Wars after the various coalitions that formed to oppose France. The brief period of peace between them was uneasy at best. In 1812, the United States, angered by British policies towards neutral shipping and impressment of American sailors, also declared war on Great Britain. The conflict lasted three years and resolved few of the original points under dispute.

At the outbreak of war in 1793, Great Britain adopted a conservative naval policy under the assumption that the French, who were dealing with the toll their revolution had taken on their naval stores and the availability of seamen and officers, would wage only a war against trade. Accordingly, a focus was placed on frigates, sloops, brigs and cutters to protect trade, and the British Channel Fleet was dispatched largely to protect the convoys sailing for the East and West Indies. Although the British were not wrong about the impact of the revolution on the French navy's strength, their overconfidence led to a dangerous lack of urgency towards the offenses the French did mount. When the French Brest Fleet put to sea at the end of 1794, the English Channel Fleet delayed long enough in setting out to face it that the French captured no small number of merchantmen and even a ship-of-the-line. After the British succeeded in driving them back to port, the French constrained their effort to a *guerre de course* for the next two years (Saxby 1992, 26-27).

In 1795, French revolutionary forces in the Netherlands helped overthrow the Republic of the Seven United Provinces. Although nominally neutral, the Dutch supported the French. Dutch exiles of the Patriot movement were living in France, and in 1795, in part at their urging, the French formally annexed the southern Netherlands. As the army moved north, the Dutch cities welcomed the French, decorating with the colors of the French Republic. British and Prussian troops in the Netherlands fled (Israel 1998, 1119). The Batavian Republic was established to replace the old government. The *Verenigde Oost-Indische Compagnie* and *West-Indische Compagnie* quietly folded during the years of occupation. The *West-Indische Compagnie's* affairs were taken over by the government in 1791 and the company was disbanded in 1794. The last VOC ship to sail for Asia left in 1794, and the last ship returning under the VOC charter sailed in 1795 (Bruijn, Gaastra, and Schöffer 1987, 194). By 1799 the VOC was dissolved and its affairs taken over by the Dutch government (Parry 1955, 206). By 1803, all the former VOC dockyards were shut down (Israel 1998, 1127).

With Spain and the Netherlands now on the side of the French, their combined fleet strength actually exceeded that of Britain's, 600,000 tons to 500,0000 tons (Glete 1993, 377-378). In late 1796 the Brest Fleet once more put to sea. The main Channel Fleet found itself trapped at Spithead, waiting for the winds to change. The enemy failed to press their advantage, and having lost no small number of their ships to winter storms and a handful of frigates operating independently in the Channel, turned back without landing a single soldier in Ireland. The incident convinced the British that a permanent squadron was again needed to control the Western Approaches, and a blockade was initiated, pinning the French Brest fleet in harbor for several years. The Continental allies did succeed in chasing the British out of the Mediterranean, however, which likely affected the outcome of the war in Italy and Austria (Saxby 1992, 29; Glete 1993, 377-378).

The British soon planned the restoration of the House of Orange in the Netherlands and in 1798 landed troops. The small Dutch navy surrendered completely. By 1799, however, the combined Franco-Dutch army had defeated the British, driving them out (Israel 1998, 1126). That same year British Mediterranean forces at the Battle of the Nile defeated Napoleon, dashing French hopes for controlling the Levant. In November of 1799, Napoleon staged a bloodless coup, overthrowing the Directory and assuming control of France.

By now, the British navy again outnumbered its opponents. In 1800, its fleet was three times the size of the French one, with 546 ships to France's 204, and its combined tonnage of 550,000 tons exceed that of France and its allies at 470,000 tons. The French Revolutionary Wars had lasted more than ten years, where the previous three wars between Britain and France had lasted only six or seven years. Both nations were exhausted from the war effort. With the British dominating at sea, and the French on land, in 1802 a stalemate peace between the powers was called (Glete 1993, 376, 378).

The truce held for only a little more than a year. With the resumption of hostilities in 1803, the British accelerated their investment in the navy. Although the lens of history marks the Battle of Trafalgar in 1805 as the decisive victory that cemented British dominance of the seas, it was not a forgone conclusion at the time. France did not turn to a *guerre de course* in the Napoleonic Wars. In fact, French construction actually exceeded British construction at several points during the two wars. From 1791 to 1810, France alone launched 440,000 tons to Britain's 400,000, not counting the tonnage built by its satellites and allies. Despite this, by 1800, the British outnumbered the French fleet three to one and the Dutch fleet four to one. By 1810, Britain controlled fully half the tonnage of European warships. The difference, crucially, came from British captures. This drained the forces of its enemies and, when prizes were still serviceable, added to its own strength (Emmer 2001, 34; Glete 1993, 377-378, 382-384).

Due to the war's length and intensity, the construction of tonnage for this conflict vastly exceeded that of previous wars. In Great Britain, this expansion was largely picked up by contracts with private merchant yards. Both naval and privately contracted shipyards suffered serious shortages of oak, spurring innovation in shipbuilding techniques to consume less wood and make better use of softwoods (Knight 2003, 35). Wood was also imported from abroad, with teak from India most highly valued. It is a hardwood of exceptional strength, and its oils actually help preserve iron. It also does not expand much in the heat, sparing teak ships the year of "rest" before being sent to tropical waters that contemporary wisdom demanded for oak. The Royal Navy also commissioned the EIC to build one ship-of-the-line and one frigate per year in the shipyard in Bombay. The EIC hoped the twenty percent profit offered per ship would help liquidate some of its debt, although the yard proved to be plagued by disorganization and inefficiencies, and the contract was cancelled after the war (Lambert

2002, 143-145).

France and Britain also waged economic war against each other. In the early years of the Napoleonic Wars, the British seized French and Dutch ships in British ports, passed regulations on neutral trade with enemy colonies, and blockaded the Elbe and Weser rivers and all French ports on the English Channel and North Sea. Napoleon meanwhile sought to limit British trade with the continent through military occupation, political coalition, and tariffs. In 1806, the British extended their blockades to the whole stretch of coast from Brest to the Elbe River. Napoleon retaliated in 1806 and 1807 with decrees that established the Continental System—they prohibited trade with Britain, seized British property in French occupied areas, and declared any vessel that had called at or was sailing to a British port and all British goods fair prize. The British responded by declaring that all neutral ships trading with the Continent must first stop in British ports (Davis and Engerman 2006, 29-30; O Rourke 2006, 126).

Such broad decrees were not truly enforceable, but they justified the capture of enemy and neutral shipping and stoked tensions with the United States. In addition, the Continental System was intended to weaken the British economy and disturb the balance between imports and exports, with the aim of reducing the specie available to the British government for military campaigns and subsidies to allied continental nations. Bullion at the bank of England fell from £6.9 million in 1808 to £2.2 million in 1814 (Davis and Engerman 2006, 30-32). Britain took over much of the inter-European trade, while trade across the Atlantic was curtailed (Glete 1993, 375).

The reduction of Atlantic trade forced the United States' economy was to turn inward, increasing production in domestic markets (Glete 1993, 375). The United States at first maintained a neutral role, again raising debate on what that meant. They argued that free ships meant free goods, which is to say that neutral ships should be able to freely carry all goods not explicitly considered contraband, even those from belligerent countries. The British countered with the Rule of 1756, which stated that trade not customary in times of peace was not neutral trade (Førland 1993, 152). British seizures of American ships caught trading with France and its allies, tensions over the continued economic blockades enforced by Britain after France dropped restrictions for American traders, and the impressment of American sailors by the British navy stoked tensions between the United States and Great Britain. The US entered the war in 1812, diverting British forces to North America.

Frustrated by the Batavian Republic's lack of cooperation with raising money and with the blockade against Great Britain, Napoleon installed a new regime in 1804, and then a monarchy under Louis Bonaparte in 1806 (Israel 1998, 1129). By 1808 nearly every shipyard, dock, and workshop in the state of Zeeland was closed (Israel 1998, 1127-8). In 1810, France officially annexed the Netherlands, and from 1810-1813 the Dutch navy was officially incorporated into the French navy. Under Napoleon, a new construction program was begun, and the Den Helder naval base was completed. Dutch trade was heavily affected during these years by the British blockades and French economic retaliation (Bruijn 1993, 211-212). In November 1813, with the defeat of Napoleon, the House of Orange was restored (Bruijn 1993, 211-212). The Dutch economy would take longer to recover, with the Industrial Revolution not reaching the

Netherlands until 1860 (Mokyr 2000, 509).

Coalition forces entered Paris in 1814, and King Louis XVIII retook the throne of France under a constitutional charter. Initial peace agreements were concluded with the Treaty of Paris, signed in 1814. Napoleon, originally exiled to the island of Elba, staged a coup in 1815, but was again defeated after the Hundred Days' campaign. The Congress of Vienna, which continued work through the Hundred Days, reestablished the countries conquered by Napoleon. Britain gained Malta, the Cape of Good Hope, and Ceylon (Sri Lanka). The United States concluded its peace with Great Britain early in 1815, settling the conflict with what was essentially a draw and reestablishing the *status quo antebellum*.

The Dutch slave trade briefly revived in the years prior to the start of the Napoleonic Wars, but at a rate dramatically lower than its peak. It had never been especially profitable, and the outbreak of the war forced the Dutch merchants engaged in slaving to seek other markets (Postma 1990, 276–280, 284-285; Emmer 2001, 39-41). Both the United States and Great Britain passed laws banning the slave trade in 1807. The Dutch prince regent, Willem I, followed suit in 1814. There was no notable abolitionist movement in the Netherlands; the move was a political one to curry favor with the British during negotiations for a peace settlement (Postma 1990, 289-291). It wasn't a large concession. While other countries' trade in slaves grew in the last quarter of the 18th century, the Dutch trade had shrunk. Few traders resumed the business following the Napoleonic Wars (Emmer 2001; Curtin 1969, 216). In 1818, the British and the Dutch signed an accord for the suppression of the slave trade, granting each other rights to board ships of the other nationality suspected of being engaged in slaving and establishing courts at Sierra Leone and Surinam (Postma 1990, 289-291).

The EIC, with its forces backed by the British army and navy, rapidly expanded its territory in India in the 1790s and 1800s, despite the clear declaration in the 1784 act that "to pursue schemes of conquest and extension of dominion in India are measures repugnant to the wish, the honour, and the policy of this nation" (The East India Company Act 1793 (33 George III). Cap. LII, Para. XLII). The third Anglo-Mysore war against Tipu Sultan resulted in 1792 in the loss of half his territory, the payment of a large indemnity to the Company, and the taking of two of his sons as hostages by the Company (Barrow 2017, 87). Fears that Tipu was seeking an alliance with Napoleon led to a fourth war in 1799, with further gains in territory for the Company and the death of Tipu. In 1803, the Company claimed that the military forces of the Marathas, who controlled significant territory in central and northern India, were a threat to its own holdings. It waged a campaign against them that lasted two years. This also ended in territory gains for the Company, in addition to the establishment of alliances in the Company's favor. British naval control of the Indian Ocean was key to the military conquests in India (Barrow 2017, 86-91).

By the final years of the war, the British government found itself under significant pressure to open Asian markets to private import and export trade. The disruption of trade with the United States during the War of 1812 had led to significant unhappiness and unemployment among manufacturers and merchants who relied on the American market to sell their goods. This pressure, coupled with the growing reliance of the

Company on state subsidies persuaded the government of the need for further reform. The East India Company Charter Act was passed in 1813. It opened India trade to non-Company merchants, although the Company would hold the monopoly on China until 1833 (Sutton 2010, 10; Webster 1990, 404-406).

Pax Britannica (1815-1850)

The end of the Napoleonic Wars saw a century-long period of relative peace between European powers known as the *Pax Britannica*. The financial center of Europe began shifting from Amsterdam to London in the late 1700s, and was hastened by the collapse of the Dutch Republic. By 1815 there was no question that the change was complete (Spufford 2006, 167-169). Britain was industrializing rapidly, its economy experiencing unprecedented growth with little indication of slowing. The Netherlands, preoccupied with needed political and financial reform, did not follow its lead until the end of the century (Mokyr 2000).

Dutch trade during this time period was conducted largely on private accounts, about which little has been written. The newly formed Kingdom of the Netherlands held small territories in the West Indies (Curaçao, Surinam, and Sint Eustatius) and Indian Ocean, including Melaka (Malacca). Melaka had once been one of the most important ports in the Indian Ocean for its ability to control trade between India and China. Its influence, however, had been reduced in the previous two centuries by the Dutch insistence that all trade under their monopoly pass through Batavia and by the establishment of the English port of Penang, also in the Straits of Melaka. Trade did not recover during this period of Dutch control, and in 1824 they exchanged Melaka and by extension the Malay

Peninsula for British-controlled Bencoolen (Bengkulu) (Hussin 2007, 17-20).

Britain dominated in the East, gaining complete control of the Indian Ocean and its approaches and all naval bases of note there (Lambert 2002, 149). The Company used this period to consolidate its gains in India. The first half of the nineteenth century saw numerous conflicts with Asian rulers. A second campaign against the Marathas in 1817-1818 resulted in the Company establishing direct or subsidiary control over most of India. Only the Sikh state was still strong enough to resist British control, and the First and Second Sikh Wars (1845 and 1848-1849) gained the Company control over Punjab as well (Barrow 2017). During this time a fourth Company presidency was also established covering Penang, Melaka, and Singapore in Southeast Asia in 1826, although the loss of monopoly in 1833 significantly diminished their value. During the First and Second Burma Wars (1825-1828 and 1852, respectively) they gained substantial territory to the north of that presidency (Barrow 2017, 95-97).

The EIC's monopoly on India trade ended in 1813, although it continued to engage in the home trade until a credit crisis and economic depression in the years 1830 to 1833 destroyed the Agency Houses in Calcutta (Chaudhuri 1966, 345-346). With the relinquishing of monopoly rights to the trade to China, the EIC moved into a purely politico-military role, administering British holdings in the East (Sutton 2010, 10). This did not substantially alter trade to Asia itself, which continued under the account of other London-based firms (Chaudhuri 1966, 345-346). The sale of opium and cotton were not significantly reduced by the 1830 depression. In fact the crisis led to a significant increase in the quantity of opium exported (Chaudhuri 1966, 353, 361-362). Opium sales funded the entire annual purchase of tea by 1825 (Sutton 2010, 217).

The Chinese government passed measures to limit the illegal trade and the cultural and religious intrusion of Europeans, known as the Canton system. In 1839, they seized a British store of opium valued at two million pounds. Under claims of defending the national honor and internal pressure to open the Chinese market to free trade and legal importation of opium, Great Britain declared war in 1839 (Melancon 1999, 855-858). China's demand that Europeans cease the trade in opium went unheeded, but the outbreak of the First Opium War reduced the trade of opium from 27 percent of the total exports of India in 1836-1837 to 10 percent in 1839-1840 (Chaudhuri 1966, 351-352). The end of the war did not bring the legalization of the opium trade, as British merchants had hoped, but it ended Chinese efforts to halt the trade. The Second Opium War would legalize the trade a few years after the British government assumed full control of its Asian territories in 1857 (Sutton 2010, 10).

Patterns of British shipping also changed during the *Pax Brittanica*. South America became an increasingly important commercial interest, and even more so after colonies there began to break away from Spain and Portugal. Australia, meanwhile, was beginning to flourish. The first settlement of convicts was sent in 1788 and faced dismal conditions. In the early 19th century, there was still a substantial population of convicts, but the population of free English-speaking inhabitants was also growing. While the majority of emigrants from Great Britain in the first half of the 19th century sailed to the Americas, by the 1840s, 15,000 free settlers arrived annually (Ferguson 2008, 35). Sheep farming was the staple of the economy, with exports to Great Britain rising from

175,000 pounds in 1821 to 39,000,000 pounds in 1850 (Ferguson 2008, 36).

Relations with the new United States remained tense. The Corn Laws were passed in 1815 to protect British agricultural markets. The United States responded with Henry Clay's "American System" in 1824. American political debate over the passage of such tariffs underscored the rapidly differentiating economies of the North and South. Southern cotton farmers exported two-thirds of their crop, with Great Britain as the primary importer, while Northern cotton mills struggled to compete with the higher quality goods being produced in Great Britain. Trade between the British West Indies and the United States did not recover after the war. In the 1820s negotiations between President Adams and the British government stalled, and mutual retaliations further diminished the trade. Jackson eventually signed an agreement more favorable to Southern agricultural interests than those of Yankee shipowners. The United States refused to engage in international efforts to abolish the slave trade. American imports exceeded exports by a significant margin, eventually reaching in 1836 a value $45.7 million in excess of the combined exports and carrying trade. In 1837, however, a poor harvest in England caused the Bank of England to reduce the credit available to British firms that were heavily invested in American markets. This resulted in a financial panic (Howe 2007, 502-503, 258-259, 271-273, 361; North 1961, Tables A-VIII, B-VIII, C-VIII on 233-234).

Political discontent in Canada bore fruit in a revolt in 1837. Although it came to little, it was widely recognized as symptomatic of deeper problems. The rapidly expanding United States made no secret of the fact that they wished to absorb British

Canada. Their attempts to annex the colonies during the War of 1812 had been rebuffed, but political pundits warned that Canadians might follow the American example and secede from the Empire. The northern colonies remained important to the British Empire. Its merchant marine was the third largest in the world, the forests of the region were of an important source of timber for the Royal Navy, and the naval base at Halifax was strategically important. Lord Durham, accompanied by Edward Gibbon Wakefield and Charles Buller, was dispatched to the colonies to draft a policy recommendation to prevent the loss of the Canadian colonies. His Durham Report was well received. Upper and Lower Canada were constitutionally joined in 1840, to the distress of French-speaking Quebec. 'Responsible government' was introduced in Nova Scotia in 1848, and was established in all of the Canadian colonies, including those on the western seaboard, by 1856 (Ferguson 2008, 53-55).

Simultaneously, the British government began to move away from the protectionist attitude with which it had governed trade within its empire for two centuries. The first to be repealed were the Corn Laws in 1846, an action that was intended in part to prevent another famine like the Irish Potato Famine and "maintain the social order and keep revolutionary politics at bay" (Ferguson 2008, 59). The Canadian colonies objected to the drop of market protections, but trade with the United States increased significantly with repeal. It was followed by the repeal of the Navigation Acts in 1849 and the Sugar Acts in 1852 (Ferguson 2008, 58-61).

The movement towards free trade was driven by the interests of the rising manufacturing segment, and together with the move to colonial self-governance, altered trade patterns around the world. The Industrial Revolution soon brought a revolution in transportation, too. With the introduction of steam engines, iron-hulled vessels, and screw propellers, wooden sailing vessels became increasingly less important to global politics.

CHAPTER II

PREVIOUS RESEARCH*

Trends Over Time

Several previous studies of shipping have asked the question of whether shipping speed increased during the 18th and early 19th centuries, but no clear answer has emerged. The majority of these studies were based on port records, measuring the speed of ships by looking at the total length of the voyage. Since ship speed is dependent on course charted and variable seasons and weather conditions, as well as the design of the ships, such comparisons are imperfect. Furthermore, few of these studies have considered explanatory variables such as the nationality of the vessel, ship size and type, or periods of warfare.

Perhaps the most influential study has been that of Walton, an economist who analyzed the speed of colonial ships traveling on various Atlantic routes using port records. He was primarily interested in overall shipping productivity on these routes, and considered ship speed as just one factor in his larger analysis. He found no particular trend in voyage lengths, which he measures using the time between leaving one port and arriving at the next, before the American Revolution. He downplays any effects of technological improvement, stating that the changes to hulls and rigging had no important change on either ship speed or the size of crew needed to man a vessel

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(Walton 1966, 597; 1967, 73-74). Another economist, North, extended Walton's study to 1860; he determined that ship speed does increase after the American Revolution, so that voyage times of transatlantic packets are cut to half to two thirds of their pre-Revolution average. The source of his data is not specified (North 1968, 962-963).

Morgan (2004) looked at transatlantic voyages by vessels leaving from Bristol and sailing to the Caribbean and British America during the years 1749 to 1779. He found no clear trend: the length of the crossing increased slightly for ships that stopped first at Ireland before traveling on to Virginia or Jamaica, but decreased by 9.5% for ships sailing directly to Jamaica from Bristol. He argues that since ships were only making one voyage per year at this time, voyage length was not very important to merchants and therefore speed was not sought by ship owners. However, a number of factors did call for an increase in speed, including trade in certain perishable cargoes, significantly higher profits for the first ship to bring a crop into a port, and reductions in operating costs and shipboard mortality. By the 19th century, it was also considered a mark of progress (Riley 1981, 651; Chapelle 1967, 3).

Bruijn, Gaastra, and Schöffer (1987, 2013a, 2013b) compiled a comprehensive list of Dutch East India Company (VOC) voyages, which they published in a three volume set available as books and a downloadable database. They consider the question of shipping speed at length, although their analysis does not use statistical methods. They identify a number of potential factors that may have affected voyage lengths. Short voyages were encouraged by the VOC through a system of bounties for fast passages, but there were other factors beyond the length of time at sea to consider when planning a voyage (1987, 56, 61, 71, 111). Weather in the Indian Ocean is high seasonal, with the direction of the monsoon winds reversing between summer and winter, and accordingly the date of departure was highly significant. Three major fleets set sail each year from the Netherlands, timed to allow the ships to arrive when the weather and trading conditions were favorable: the Easter Fleet departed in May, the Fair Fleet (named for the traditional September Fair) in October, and the Christmas Fleet in December. Smaller numbers of ships also departed between the fleets (62-63). The major port of call en route was the Cape of Good Hope, but it did not provide safe anchorage in winter months. In 1742, as a reaction to the loss of numerous ships anchored there, the decision was made to use nearby False Bay instead, and to reduce the size of the Christmas Fleet. Since ships departing in the warmer months had significantly longer voyages than at other times of the year, this significantly increased voyage length (68-72). The return voyage was easier, with the only significant threat being the risk of cyclones near Mauritius from January to March. The 1742 sailing instructions dictated two return dates, one in October and one in late January to avoid this, although more ships were allowed to depart outside of these months towards the end of the century. This lead to significantly less losses, as well as ensuring that merchants in the Netherlands knew whether to expect a second fleet to arrive with additional goods (78, 80-81). Ships were not required to sail in convoy to the Cape, and in the second half of the 18th century departed directly from Batavia, Ceylon, Bengal, and Canton. Three fleets departed from the Cape to the Netherlands, and were met by an escort of several warships and supply ships with fresh provisions in the waters near the Shetlands or the English Channel (84-86, 87). This also served to deter illegal stops in English ports.

Route also affected passage time. Passing the British Isles to the north of Scotland (called the "backway") instead of through the English Channel was estimated by contemporaries to add a month to the voyage, but was preferred during times of war or when privateers were active. Ships sailing through the English Channel were also known to stop in southern English ports to await better weather and engage in illicit smuggling, which could likewise add significant time to the voyage. By the middle of the 18^{th} century, the backway was less often used for outgoing voyages, although it was still frequently used during returning voyages, especially in times of war (63-64). Overall, Bruijn, Gaastra, and Schöffer found no clear trend in voyage length over the life of the VOC. Like Walton and Morgan's data, Bruijn, Gaastra, and Schöffer's database includes only the ports of departure and arrival, which does not accurately represent the distance covered during each voyage as there were multiple routes between ports; overall voyage length was estimated but not statistically accounted for in the analysis.

However, a growing body of work supports a slight but steady general increase in speed for sailing ships over the eighteenth and nineteenth centuries. Ville (1986) found that the voyage time of coal-carrying colliers sailing from northeastern England to London decreased from 1700 to 1850, allowing them to make more trips per year. Solar and Hens (2013) looked at voyage lengths of British East India Company (EIC) ships sailing for India and the East Indies from 1770 to 1829. They used the number of days from departure in England to arrival in Asia as a measure of speed. They found that ship speed increased on average 0.3 percent annually, controlling for tonnage, age of ship, destination, number of stops, and season of departure. However, while they had the number of stops available, they did not have the length of the stops, so it is not clear whether voyages became faster due to decreased sailing time or decreased turn around time in ports. They also unfortunately omitted all voyages during periods of warfare under the incorrect assumption that trade was so significantly interrupted by hostilities that it would not be useful to analyze it.

Klein (1978, 189-193) found that the transatlantic voyage times of French slave ships sailing across the Atlantic to Saint-Domingue from the Gold Coast and Angola also showed a consistent decline in length in the 18th century, although this increase in speed was not shared by ships leaving from Guinea. This trade was highly seasonal, with the vast majority of ships arriving between January and June, the peak harvesting time in the West Indies (189-191). He does not speculate on the possible reason for the decrease in sailing time, although he notes that the growing dominance of ships in the 100-149 ton range (54% of all English ships arriving in Jamaica by the 1780s, with similar figures for ships of other nationalities) may be indicative of the appearance of a specialized type of vessel in the this trade.

(Rönnbäck 2012, 476, 481, 485) also looked at slave ships, examining 2,886 voyages from the Transatlantic Slave Trade Database, most of which fell between 1675 and 1850. He measured speed using the distance between ports divided by the length of the journey, and found that the speed of the ships increased steadily by 0.3-0.5% per year, from an average of around 2 knots to slightly more than 4 knots. This resulted in the length of the passage dropping from 90 days in 1700 to 60 days in 1800. He found no difference between French and British ships, but did observe that larger ships (measured by tonnage) were faster, which he attributes to greater sail area. The trend was fairly steady over time.

One previous study has used the CLIWOC database to analyze ship speed. Kelly and Ó Gráda (2014) separately considered British East India Company (EIC) ships, Royal Navy ships (excluding those over 80 guns), and Dutch frigates. They measured ship speed using the distance the ship traveled each day, calculated trigonometrically using each day's entries of longitude and latitude. For much of this time, longitude could not be directly measured and was calculated by dead reckoning, with corrections made when landmarks were spotted. The CLIWOC researchers corrected gross errors in longitude and latitude measurements where observed (García Herrera et al. 2005, 6). Kelly and Ó Gráda omit any consideration of the size (length or tonnage) or type of the ships. They consider wind speed, wind angle relative to the ship's course, and longitude and latitude as explanatory variables; the latter two are included to account for geographical differences in currents and wind patterns.

Each category of ship was analyzed separately for each wind speed. For British EIC ships and Dutch frigates, they concluded that ship speed was relatively steady from 1750 until the 1780s. During the 1780s, ship speed sharply increased by about 10%, which they attribute to the introduction of copper plating. From the 1780s to the 1820s, the speed of ships increased steadily, by an additional 20%. Little change is evident from 1830 to 1850. Royal Navy ships were found to be slower on average than British EIC ships, but they followed a similar pattern over time as the merchant ships. An overall increase of about 1.5 knots (in moderate breezes) is evident in the data for all three categories of ships; greater gains were made at lower wind speeds than higher ones. No statistical comparison was made between the groups.

Technological Change

It was during the 18th and 19th centuries that shipbuilding transitioned from a craftsman's tradition, where shipbuilders learned their trade through apprenticeships and ships were designed with a heavily reliance on tradition and the judgment of experience, to an engineering practice, where ship design was heavily influenced by predictions based on scientific theories about the natural world. However, shipbuilding is a highly conservative field, since vessels are extremely costly to build and they are all that stands between their crew and cargo and the inhospitable oceans in which they operate. Additionally, there are strong constraints on the overall size and form that can be achieved in a wooden sailing ship, and it is not until the introduction of iron hulls and steam power in the 19th century that intense innovation disrupted the centuries old traditions of shipbuilding. Accordingly, there is no consensus among scholars on how much the design of ships improved during the period from 1730-1850. Because of the numerous factors that affect ship design and performance, identifying technological improvement is difficult, but there are a few variables that may shed some light on the question.

Some have argued that this was in fact a period of little to no change. Standardization of scantlings[3] constrained the designs of both naval and VOC ships. Glete (2000, 410) argues that design of British naval ships remains "fairly stable" and until the 1790s, with "no further improvement actually achieved," despite a system that specified that the designs of at least two different naval architects would be constructed for any rating in order to foster internal competition. Dutch naval design also stagnated. In the 1720s, British shipwrights were hired for Dutch shipyards, but Glete argues "there is no sign that the British influence caused any radical change in warship design" (Glete 2000, 411). Nearly all Dutch East India ships were built to the 1749 set of establishments until the company's collapse in the final decade of the 18th century. During the Fourth Anglo-Dutch War, the company was forced to purchase or lease vessels. In addition a handful of packet boats (pakketboots) and pinks were employed in the final years of the company (Bruijn, Gaastra, and Schöffer 1987, 36, 47-48, 50). North (1968, 967), citing Walton's 1966/7 analyses of speed of shipping, discounts any significant technological improvement in ships prior to the 19th century, arguing that what increases in speed did occur were "not a result of new knowledge in ship design." He draws this conclusion on the basis of records of individual ships from the seventeenth century making the transatlantic passage at similar speeds as ships in the nineteenth century, but he does not look at average speeds over time.

[3] The measurements for structural parts of a ship. These are often established in the contract between a shipwright and the person purchasing or commissioning the vessel.

The tons per man ratio, which indicates the number of tons of ship one crew member could handle, increased during this time, which could suggest improvements in rigging that allowed ships to operate with smaller crews. Tons per man of ships entering New York increased from 6-7 tons per man in the mid-1700s to 22-26 tons per man in the mid-1800s (North 1968, 959; Albion 1939, 398). North attributes the rise prior to 1800 to a decrease in piracy, and the rise after 1800 to an increase in overall size of the ships. That is, he attributes the larger crews in earlier years to ships carrying larger crews than needed in order to defend themselves against attack. His evidence for this decrease in piracy is a decrease in number of guns per ship and falling insurance rates (North 1968, 959-960). However, insurance rates are not a direct measure of the risk of piracy, as they are influenced not just by risk (which included ships lost to weather, foreign navies, and privateers as well as pirates, and the availability of convoy escorts) but also by the overall numbers and tonnages of ships traveling and the number and financial backing of insurance companies operating at the time. The number of insurance companies, as well as the total risk amount of shipping they covered, increased dramatically during this same period (John 1958).

An increase in the tons-per-man ratio is well documented for the middle decades of the 18th century, and other analyses of this trend do attribute it to technological improvements. French (1987, 630-631) and Minchinton (1989, 70-71) document a steady increase in tons-per-man over the period 1726-1772, and both ascribe it to improvements in operating efficiency from increased size of vessels or improved ship technology Although the number of guns carried (observed by tons-per-gun) increases notably in periods of war, hostilities have only a small effect in tons-per-man, suggesting that manning of British merchant vessels was not predominantly driven by risk of capture (Table 1). Data quoted by Davis (2012, 67-73) also shows clear improvement in tons-to-man ratio over the period 1725-1766, with significant variation between routes travelled. He unequivocally ascribes the increase to technical changes, writing, "this drastic reduction in crew size in the middle decades of the eighteenth century bespeaks a technical advance of some magnitude" (Table 2).

Van Lotturn and van Zanden (2014) also note significant difference in tons-to-man ratios between northern and southern European ships, and document higher basic literacy and numeracy rates among northern sailors, as measured in the records of the Royal Navy's Prize Papers. Ships with the highest tons-per-man also had the highest rates of literacy and numeracy, suggesting higher overall skill level. They attribute this to the lack of restriction on employing foreign sailors in the German, Dutch, and Scandinavian fleets, unlike in the French and Spanish fleets, creating an open market that made it easier for ship masters to hire more skilled labor. They do not consider technological differences in the ships.

Gains continued in the late 18th and early 19th century. Söderberg (2010, 7) examines ships leaving Stockholm in 1750, 1780, and 1820, and observes an overall increase in tons power man from 14.4 to 16.1. Non-Swedish ships increase from 15.6 to 19.5, or about twice as much as Swedish ships, which increase from 14.4 to 16.1. Solar (2013, 640) also finds an increase in tons-to-man ratios for ships sailing to Asia between 1770 and 1830. American vessels at Leghorn show an increase in tons-per-man from just

Table 1 Tonnage statistics for British ships trading in London, Virginia, and Jamaica by periods of peace and war, 1726-1763. (1) Data from London Shipping Lists (French 1987, 630-631) (2) Data from Minchinton, King, and Waite (1984, 54-87); Minchinton (1989, p 70-71)

VESSELS TRADING BETWEEN LONDON AND VIRGINIA[1]

	1725-1727 (Peace)	***1735-1738 (Peace)***	***1739-1746 (War)***	***1749-1755 (Peace)***	***1756-1763 (War)***	***1764-1769 (Peace)***
Average Tonnage	138	140	149	168	159	182
Tons Per Man In	9.0	10.1	9.5	11.7	11.7	13.9
Tons Per Man Out	8.1	10.2	9.5	11.7	11.8	13.9
Tons Per Gun	27.7	25.9	16.6	57.3	35.7	681.2

VESSELS TRADING BETWEEN LONDON AND JAMAICA[1]

	1744-1748 (War)	***1752-1755 (Peace)***	***1762-1763 (War)***	***1764-1765 (Peace)***
Average Tonnage	163	153	194	198
Tons Per Man In	6.9	10.6	10.1	11.0
Tons Per Man Out	7.4	10.5	10.3	11.0
Tons Per Gun	12.8	39.8	24.7	92.0

BRITISH SLAVE VESSELS TRADING WITH VIRGINIA[2]

	1726-1738 (Peace)	***1739-1746 (War)***	***1749-1755 (Peace)***	***1758-1763 (War)***	***1764-1772 (Peace)***
Average Tonnage	95	85	104	69	118
Tons Per Man	4.8	4.0	4.4	4.4	5.2
Number of Vessels	59	48	41	30	11

Table 2 Tons-per-man of vessels arriving in London by port of departure and tonnage class. Adapted from Davis (2012, 68, 70), data from London Shipping Lists.

	300 tons & over	***200-299 tons***	***150-199 tons***	***100-149 tons***	***50-99 tons***	***Under 50 tons***	***Avg Increase 1726-1766***
Norway	21.9	19.0	17.0				9.7
Riga and Petersburg	21.9	17.5	15.1	13.3	11.4		5.9
Hamburg and Bremen		18.9	15.7	13.3	11.4		4.2
Holland			16.5	13.1	10.6	8.1	3.0
France				14.8	10.9	6.9	2.5
Spain and Portugal		16.5	14.5	12.4	10.4	7.0	3.5
Virginia and Maryland	18.7	16.6	13.3	12.5			4.8
Jamaica	16.0	14.8	12.2	10.5			5.8
Other West Indies	15.8	14.5	13.5	11.0	7.9		3.7

under 11 to around 18 (Keene 1978, 689). Given the range of routes, nationalities, and size of vessels covered by these analyses, it is safe to conclude that technical developments drove increases in tons-per-man ratios.

There are factors that suggest that improvements in ship design would be expected. Ship theory, the science explaining the physical behavior of ships, had its origin among the French scientists of the Academy of Science, who knew little about practical shipbuilding. By the 18th century it had developed to the point that shipwrights were beginning to use it. A number of schools opened throughout Europe to train shipwrights in math and science (Ferreiro 2007, 283-285, 289). British shipwrights, too, began to shift towards using mathematics in designing ships, although they resisted the formal schooling of an engineer in favor of the traditional master-apprentice relationship. British scientists showed a preference for experiments and scale model tests rather than theoretical models (Ferreiro 2007, 296-298). Nor did knowledge gained in one country remain there. It was common for well-respected shipwrights from one country to be brought to another, where they were often paid well. "Spy" missions were organized by some chief shipwrights to improve their knowledge of the strengths and weaknesses of the navies of other nations. Treatises on shipbuilding were also frequently published in multiple languages.

Actual results from this research were mixed. Real gains were made during the 18th century towards understanding the factors affecting the stability of ships. The invention of the metacenter, the theoretical point beyond which the center of gravity of a vessel must not rise, by Pierre Bouguer in the 1740s allowed shipwrights to calculate an important measure of stability prior to construction (Bouguer 1746, 258-264). In addition, the introduction of calculus allowed accurate calculations of displacement for the first time (Nowacki 2006, 6-12). However, useable theories describing the forces that affect how a ship moves through water proved more elusive. The laws that govern hull resistance, sail forces, and the maneuvering of ships were not accurately described until later (Nowacki 2006, 10-24). In some cases, inaccurate understandings had adverse effects on ship design.

Fincham (1851, xlii), for example, writes, "Inquiry into the theoretical conditions of ship-building was almost wholly confined to the mathematicians of the continent of Europe, engaging scarcely any regard in England during the whole of the [18th] century, until nearly its close... but whilst the treasures of mathematical learning were accumulating with the view to aid this important subject, its extreme complexity admitted of but very slow progress towards useful results; and it is interesting to observe, that whilst the Royal Academy of Sciences in France continued year after year to offer its prizes to the best writers on definite subjects connected with naval architecture, and drew forth the talent and labour of some of the most eminent men of that and other countries, yet their writings show but a very small amount of results in the improvements of the art. Indeed, the practice of ship-building can hardly be said to have improved from these purely theoretical efforts..." Despite the progress that had been made in understanding hydrostatics during the middle of the 18th century, Charles Romme notes in 1787 that the best naval architects in France could not explain what went wrong in the design of three ships that were "remarkably crank."[4]

Even where scale models and mathematics did produce improvements, it was not always due to an accurate understanding of the physical world. John Scott Russell developed the wave-line theory in 1835, positing that reducing the bow wave created by the movement of a ship through water would improve the speed of the vessel. He developed a set of ship lines with concave waterlines in the shape of a sine curve in the bow and cycloid waterlines aft, which he assumed would have no wave resistance. By testing scale models of this design, he determined that it had a smaller bow wave than the more traditional "cod's head and mackerel tail"[5] ship design (a blunt bow and tapered aft section). These new vessels had greatly reduced cargo capacities, however, and Russell counseled shipbuilders to fill out the lines as needed and according to their best judgment. Application of the design produced mixed results. The yacht *America*, designed by George Steer using the wave-line theory, so handily defeated its fourteen opponents in the Hundred Sovereign's Cup that the race was renamed after it. However its speed was not due solely to this design, as the *America* also soundly defeated Russell's own yacht *Titania* a week later. James Napier's steamers, on the other hand,

[4] L'arte de la marine, Charles Romme, p 106, cited in and translated by (Fincham 1851, xlii-xliii)

[5] This description of the shape of a ship of good design comes from the *Fragments of Ancient English Shipwrightery*, written by Matthew Baker around 1570. The description is likely a justification for the common form of ships rather than a theoretical design for ships. The basic shape persisted over the centuries, although the exact form and proportions changed.

although built using the wave-line theory, were poor performers who brought no profit (Ferreiro and Pollara, 414-415, 421-422, 427-428, 432-434).

Chapelle (1967, 411-414) analyzed the hull forms shown in the lines drawings of 103 clipper ships in order to determine what earned them their reputation as the fastest sailing ships ever built. He concludes only that the substantial gain in speed achieved by clippers was due to an increase in size and especially length, and not any "important basic gain" in hydrodynamic design. Longer ships are inherently faster, all else being equal. Hydrodynamically, there is a noticeable decrease in viscous pressure drag (hull resistance) when the ship's length to breadth ratio exceeds 4.0, with gains increasing with higher ratios (Nowacki 2006, 40). Even in ships with smaller length-breadth ratios, larger ships are faster than smaller ones, since they can carry more sail and handle better in strong winds and heavy seas (Chapelle 1967, 29).

The advantages of length were well known at the time, but a lack of understanding of how to prevent hogging,[6] prevented shipwrights from taking advantage of it. Since hogging causes the seams of a ship to split apart over the course of the ship's life, the maximum length obtainable for a wooden vessel was long limited by this phenomenon. The introduction of diagonal braces by the British after Trafalgar allowed builders to push past the previous limits on ship size. Nowacki notes that it is only with the successful use of diagonal braces that British warships reached and exceeded a length-breadth ratio of 4.0 (Nowacki 2006, 32, 38, 40, 44-45). Both average length and overall size of ships increased throughout the 18th and 19th centuries.

[6] The tendency of the ends of wooden vessels to sag downward over time, relative to the midships.

Perhaps the single most important innovation with regards to speed was the introduction of copper plating, which increased speed by preventing fouling (Bingeman et al. 2000, 222; Kelly and Ó Gráda 2014). It also decreased the need for repairs and allowed ships to stay at sea longer. The Royal Navy copper plated all of its ships starting in 1779. So significant was the decrease in necessary maintenance, that by doing so it was estimated that it increased the effective strength of the navy (in terms of the number of ships actually available to deploy) by one third (Rodger 2005, 344-5). The East India Company (EIC) soon followed, with 22 of its 26 ships then engaged in the trade with Asia copper plated by 1788. Conventional wisdom stated that ships could only survive, at most, five voyages to and from Asia, but it found by 1790 that copper plated ships remained in good enough shape to safely make a sixth voyage. Furthermore, the EIC saved two months on the journey there or back, although the seasonality of shipping in the Indian Ocean meant that this gain in time did not result in additional cargo runs (Bruijn, Gaastra, and Schöffer 1987, 51; Harris 1966, 565-566). The Dutch East India Company (VOC) was slower to follow: initial trials were made in 1788, but never followed through with copper plating all vessels due to the cost and concerns about the damage canals would do to the plating (Bruijn, Gaastra, and Schöffer 1987, 51-52). The gain in speed that copper-plating a vessel produced was well recognized in contemporary accounts (see, for example, Knight 1973, 299-300).

Nationality

Historical sources reveal that Dutch ships had a poor reputation among sailors during this time (Boxer 1982). Isaac Titsingh, a Dutchman in the East Indies, complains in a letter in 1793[7] that Dutch sailors were given "*een schraal scheepsrantsoen, op zijn best een hangmaat, en aanhoundend zwaar werk*" (a skimpy ship's ration, at best a hammock, and unremitting heavy work). He opted to take passage home on an EIC ship.

Cornelius de Jong van Roodenburg (1762-1838), a Dutch naval officer escorting VOC ships from the Cape of Good Hope to the Netherlands in 1792-1795, noted that the *Sybille Antoinette* reported at one point that of her crew of 130 only 16 were fit to climb the ropes, so afflicted were they with scurvy. He wrote, "*Het is onbegrijpelijk dat op 's Companies schepen zoo weinig behoed middelen tegen deze verschrikkelijke ziekte worden in het werk gesteld. Wij waren even lang in zee en echter niet in dien ellendigen staat*." (It is incomprehensible that on the Company's vessels so few preventative measures against this terrible disease are being taken. We were just as long at sea and yet not in that miserable state.) (de Jong 1802-3, Vol. 2, 216-220). Although the nature of scurvy was not truly understood at this point, the importance of fresh fruits and vegetables were known (Carpenter 1988, 43-74), and the British Navy had officially adopted the policy of issuing lemon juice to sailors in 1795 (Tröhler 2005, 522).

De Jong also complained of an old national prejudice against copper bottoms: *"…blijft men in onze Republiek uit een oud vaderlandsch vooroordeel, tegen het koperen*

[7] All translations mine, unless otherwise noted

der bodems... 's Companies schepen, wier vaart meer aan het kruipen van een slak dan aan de vlucht van arenden grenst" (…men in our republic continue, out of an old national prejudice against the coppering of bottoms…, to bind the Company's ships to a speed more like the crawl of a snail than the flight of the eagle) (de Jong 1802-3, Vol. 2, 216-220). Boxer (1982, 116) noted the 'deep-waisted Indiamen' were considered sluggish and unhandy compared to English and French ships.

Others voiced similarly low opinions. Dirk van Hogendorp, aboard the naval vessel *Utrecht*, complained in 1783 that their pilot believed that the sun revolved around the earth, the moon was created anew each day, and it was not only impossible to calculate longitude at sea but an impiety to attempt it (du Perron-de Roos 1943, 129).[8] Not that this prevented the vessel from arriving at its destination. By coincidence, the 1783 voyage of the *Utrecht* was included in the CLIWOC database. They made the round trip voyage in 182 days, averaging a respectable 80.8 nm (149.6 km) per day and a best day's run of 190 nm (351.9 km). Such beliefs were not held by all Dutch navigators, but the VOC was conservative in adopting new navigational methods. Despite the publication of longitude charts calculated from the moon's position in 1760 and John Harrison's invention of a chronometer that could keep time accurately at sea in 1735, the sextant and chronometer needed for the two methods, respectively, became standard issue for the VOC only in 1788. Both instruments were very expensive, and because

[8] *Le premier pilote de notre vaisseau soutenoit que le soleil tournoit autour de notre terre qui se trouvoit au centre, que n'en n'étoit plus clair, qu'on le voyait. Il ajutoit qu'a chaque lune Dieu en cré une nouvelle; qu'il ne falloit pas s'en étonner, puisque Dieu est tout-puissant. Il étoit impossible, suivant lui, de trouver les longitudes en mer; il y auroit même en de l'impiété a le tenter: Dieu ne le vouloit pas.* Correspondance Dirk van Hogendorp p 129

VOC ships nearly always travelled in convoy on the Europe-Asia route, sufficiently accurate calculations of position could be obtained by averaging the values obtained by dead reckoning from each of the ships traveling together (Bruijn 2011, 284-285).

A British passenger on board the Dutch *Held Woltemade* in 1780 noted with surprise that the captain was a liberal-minded man, who "laughed at the old system of navigation pursued by their [Dutch] ships, which although known to be erroneous was persevered in, merely because it had been so for more than a hundred years. One of these follies was that of shortening sail (no matter how the weather) in certain latitudes. His mode of conducting the fleet was precisely the same as in our service, and no British commander could carry sail in a better style than he did" (Hickey 1919, 230).

Overall, a picture emerges of an organization that, threatened by the intrusion of British and French competition, relied increasingly on strict, formal guidelines at the expense of efficiency. The 1747 revision of the prescribed route yielded a stricter set of instructions (Mörzer Bruyns 1992, 146) at a time when other companies were issuing more liberal instructions and relying on the judgment of their navigators (Bruijn 1980, 260). Captain J.S. Stavorinus, a Dutch captain, notes in his memoirs that in 1778 he and the four ships he was sailing with ignored the rules and followed the shorter course he knew was being used by ships of other nationalities, while noting in their logbooks the course they were expected to follow (Bruijn 1980, 260). After the dissolution of the VOC, total passage times for Dutch merchants decreased noticeably (Bruijn 1980, 260).

It was also an organization increasing faced with financial constraints. In 1722 and 1737, they lost three entire fleets, each in a single day and two of which while anchored at the Cape. The twenty four ships lost represent 10% of the total losses of the VOC over its entire lifespan (1602-1795) and must have been a serious blow to the company (Bruijn 1980, 261). De Jong, in a letter dating to 1793, wrote that Dutch ships, strapped for money, were "*zijn wel eens in het onaangenaam geval, van met oude touwen te ankeren*" (sometimes in the unfortunate situation of having to anchor with old ropes), a factor which he considers the reason for the many losses in the Indian Ocean (de Jong 1802-3, Vol. 1, 20).

British ships enjoyed a better reputation. Merchants from Ostend (then controlled by Austria), who bought retired East Indiamen for their own trade with the East during the 18th century, preferred English-built vessels as they could get two or three additional voyages out of them, while Dutch-built ships were unfit after a single voyage (Permentier 1993, 78-79). Jacomo de Pret, for example, wrote "*La Compagnie d'angleterre fait quatre voiages en Asie à ses vaisseaux ensuite elle les vend. Nous en avons achetté ei fait encore deux à trois voiages avec les mêmes vaisseaux de sorte que le même navire a été 6 à 7 fois aux Indes orientales*." (The English Company makes four voyages to Asia in its ships and then sells them. We bought them and made two or three more so that the same ship was 6 or 7 times in the East Indies.) (Degryse 1976-1977, 19-20).

The quality of British naval ships during this period was considered by contemporary administrators to be inferior to contemporary French naval vessels (Ferreiro 1998, 102; Davids 2016, 13-14). By 1750, continental scholars were beginning to apply advanced mathematics and early theories on hydrodynamics and hydrostatics to ship design.

France formed the first core of *constructeurs* (naval architects), shipbuilders trained in formal mathematics and theory alongside hands-on dockyard training. British shipwrights, on the other hand, resisted the professionalization of their discipline, which would have come at the expense of the traditional master and apprentice structure that had long been how new shipwrights were trained.

The Society for the Improvement of Naval Architecture was formed in 1791 with the explicit aim of applying hydrodynamic theory to the design of British ships. Their belief in the superiority of French ships and the usefulness of the emerging sciences of hydrostatics and hydrodynamics was overstated. In practice, the French and British navies built ships that reflected their different strategic objectives. British naval vessels were built heavier and could carry sail in almost all weather conditions, appropriate for being at sea for long stretches, such as during blockades and escorting convoys of merchant ships. French ships were more lightly built, and frequently designed to maximize speed in optimal weather conditions; this made them suitable for missions such as chasing and attacking merchant ships (Gardiner 1979, 271-272). It also reflected the fact that French ships' reputations—and by extension, the reputations of French shipbuilders—were established during initial sea trials in fair weather (Rodger 2003, 9-10). Although it received the most theoretical attention, hull shape was likely the least important factor in determining speed, compared to rigging, the skill of the captain, the training of the crew, and the upkeep of the vessel (Ferreiro 2007, 177). One study comparing the speed of British and French naval ships found that French-built naval ships were slightly faster than British-built ships—when owned and manned by the

British navy. British-built/British-manned ships outperformed French-built/French-manned (Brown 1990, 156-159, 176-180).

Ultimately, both British and French ships were improved through the gradual process of trial and error. British naval shipyards also benefited from the experience of private yards, as these yards were often tapped for building and repairing naval vessels, while French naval yards remained under centralized control. This may explain why British naval shipwrights also more readily adopted new technologies, such as the rudder wheel in the early 18th century and copper sheathing in the mid-century; French naval constructors took thirty and twenty years longer, respectively, to adopt the same technologies (Ferreiro 1998, 192; 2007, 176-178; Davids 2016, 13-14).

CHAPTER III

DATA AND METHODS

CLIWOC Database

The Climatological Database of the World's Oceans (CLIWOC) project sought to obtain data on climatological conditions from the century before the widespread use of barometrical instruments by using the observations of sailors at sea. The project, funded by the European Union (UE contract EVK2-CT-2000-00090), was conducted from 2000 to 2003 by researchers from five institutions: Universidad Complutense de Madrid, Spain (coordinator); University of Sunderland, UK; Royal Netherlands Meteorological Institute (KNMI), the Netherlands; IANIGLA, CONICET, Argentina; and University of East Anglia, UK (García Herrera et al. 2003, 4). A great deal of additional information on the ships themselves, events on board, and sightings of wildlife were also included for the express purpose of facilitating interdisciplinary research. The final database is freely available online (Garciá Herrera et al. [2003]).

The amount of information available varies by country and ship, but individual entries usually include the ship name, the port of departure, the port of destination, distance travelled in the past 24 hours, coordinates from the noon location, and a qualitative description of the wind and weather. In addition, ship type, number of guns, tonnage, length, size of crew, and notable events such as illness and deaths are also included for many of the ships. Coordinates were calculated on board daily using dead reckoning; when a landmark of known location was sighted, the coordinates noted in the logbooks were corrected going forward but earlier entries were not customarily changed.

This results in abrupt jumps in the data recorded, and the CLIWOC researchers corrected the courses charted using the known locations of the ports of call. Wind speeds were standardized to the Beaufort scale: the researchers report that the terms used by each nation's seafarers were consistent enough that they can be matched to the modern numerical scale of wind speeds. For a description of the standardization process and an analysis of its accuracy, see (García Herrera et al. 2005).

Although extensive, the database represents only a small portion of the surviving logbooks available for study: the researchers estimate that 120,000 logbooks may survive in Western Europe alone (Wheeler et al. 2007), and efforts to expand the available databases continue with the RECLAIM project, which also seeks to include logbooks from other countries, including the United States (Wilkinson et al. 2011).

The CLIWOC database has drawn little attention outside of climatological studies, however. Wilkinson (2005) notes its potential for research in other fields, and it drew some attention from historians for its ability to generate maps of shipping routes (D'Efilippo and Ball 2013). but only one detailed analysis on any topic other than the climate has been published: that by Kelly and Ó Gráda (2014) which was discussed above (see Chapter II).

Variables

Ship Names & Ship Year

It was common practice throughout this period to reuse names of older ships on new vessels, so that there are multiple entries in the CLIWOC database where the same name refers to markedly different vessels. Every effort was made to distinguish between vessels. Tonnage, where provided, was the most useful variable for this endeavor, as it could both distinguish between two vessels and be compared to external references (see Length and Tonnage section for discussion of sources used). Rebuilds of a vessel were not separated into two records unless the tonnage changed notably. As a general rule of thumb, a maximum lifespan of thirty years was assumed for vessels: that is, where other sources were not useful in separating two entries under the same name, they were considered different ships if a given voyage took place thirty years or more after the ship year. This is based on the typical lifespan observed in the data on Royal Navy vessels taken from (Colledge and Warlow 2010): ships included in my analysis with known dates of construction and retirement taken from Colledge and Warlow's work have a mean age of 24.37 years and a standard deviation of 13.09.

Ship year represents the year the ship was built—specifically the year the ship was launched—if known. If not, the first year the ship appears in the database was substituted. This information was largely added from external sources.

Nationality and Company

Ships were classified according to the **nationality** and **company** that owned the ship, as recorded in the CLIWOC database. This represents the nationality of the ships' owners at the time of the voyage, which is not necessarily the country where the ship was built. It is almost certain that some of these ships were foreign built, having been either purchased or captured from other countries, but it is not possible to account for this at present. It is safe to assume, however, that the majority of ships would have been built in the country of ownership, as both Great Britain and the Netherlands had strong traditions of shipbuilding at this time. Accordingly, nationality of ownership will be considered here as a stand-in for different countries' schools of construction.

The following companies or institutions were represented in the database (see Appendix I): British Royal Navy, British East India Company (EIC), Dutch navy, *Vereenigde Oostindische Compagnie* (Dutch East India Company, VOC), *Middelburgsche Commercie Compagnie* (Middleburg Commercial Company, MCC), *West Indische Compagnie* (Dutch West Indies Company, WIC). There were also one British vessel classed as merchant navy and a number of Dutch vessels whose ownership was attributed to private merchants. The number of ships considered in this analysis, divided by company, is shown in Table 3. The figures provided in this table do not include the vessels excluded from all analyses; see the Exclusions section for more detail. Appropriate counts for each analysis are provided.

Table 3 Sample sizes for British and Dutch ships by company.

BRITISH			
Company of Ownership	**n Length Known**	**n Tonnage Known**	**n All vessels**
British Naval Vessels	233	367	383
British Merchant Vessels (All)	37	69	74
East India Company (EIC)	37	69	73
Merchant Navy	0	0	1
Vessels of Unknown Company	0	0	3
Total British Vessels	270	436	460

Table 3 Continued.

DUTCH			
Company of Ownership	**n Length Known**	**n Tonnage Known**	**n All vessels**
Dutch Naval Vessels	7	10	136
Dutch Merchant Vessels (All)	45	47	71
Vereenigde Oost-Indische Compagnie (VOC)	41	42	42
West-Indische Compagnie (WIC)	1	1	3
Middelburgsche Commercie Compagnie (MCC)	2	3	17
Merchant Marine & Private Merchant Vessels	1	1	9
Vessels of Unknown Company	0	0	23
Total Dutch Vessels	52	57	237

Ships were then broadly classified by the type of company. Most analyses simply distinguished between naval and merchant vessels, but for a few analyses, merchant ships were further separated into company-owned ships and privately-owned ships. The largest company sample came from the VOC ships, with the other companies having smaller sample sizes (see Table 3). A handful of Dutch ships were listed under private merchants (either simply "*particulier*" or with a specific name given) or as merchant marine, and these were all classified as 'Merchant.' One British ship was listed as "merchant navy." Ships of unknown company are assumed, when relevant, to be privately-owned merchant vessels. There were only three British-owned ships listed as belonging to unknown company.

Type of Ship

Type of ship was also considered as a variable where applicable. Naval ships were classed by rating. British naval ships were classed as 2nd through 6th rate based on the number of guns; there were no 1st rate ships present in the database (Table 4). There were also some vessels listed as bomb, store ship, transport, fireship or other classification not informative about the vessel's size or rig. An equivalent system of rating for Dutch naval vessels was not historically used (Glete 1993, 83), although a description of the ship type is provided for some ships. Ship type was not considered as a variable in the analysis of Dutch naval vessels. Ships marked as steamships were not included in any analysis.

Table 4 Sample sizes for British Royal Navy vessels by ship type (rating)

Ship Type (Rating)	No. of Guns	n (Length Known)	n (Tonnage Known)	n (All)
2nd Rate	90-98	5	5	5
3rd Rate	64-80	34	55	55
4th Rate	50-60	25	40	41
5th Rate	32-44	63	98	98
6th Rate	20-28	50	74	76
Unrated	<20	48	77	81
Storeship/Troopship	-	6	10	11
Unknown	-	2	8	16
All	-	233	367	383

The VOC built ships of standardized dimensions, officially classified into three rates, the dimensions of which changed over time. Towards the end of the company's life, they also hired or bought vessels. EIC ships were largely hired, and were not built to standardized dimensions. For this analysis, these ships are grouped into categories that are roughly equivalent to the VOC ratings, although it is important to note that this is not a rating system—that is, they are not categories based on building ships to standardized dimensions or based on contemporary divisions of types of ships. Ships were grouped primarily on the basis of tonnage and secondarily on the basis of length. The groupings are: large vessels, of more than 1200 tons, medium vessels, of 700-1100 tons, small vessels, of 550-699 tons, and very small vessels, of less than 550 tons. Sample sizes for both companies can be seen in Table 5.

Table 5 Sample sizes and dimensions for VOC and EIC vessels by ship type. Length of VOC ships is measured in *voet* or the Dutch foot, while tonnage is measured in Dutch tons. Length of EIC ships is measured in (Imperial) feet, while tonnage is measured in tons burthen (bm).

DUTCH EAST INDIA COMPANY (VOC) VESSELS			
Ship Type	**Length**	**Tonnage**	**n**
1st Rate	150 vt.	1100, 1150, 1210 ton	22
2nd Rate	136, 140 vt.	850, 880, 898 ton	11
Hired	122-136 vt.	500-686 ton	3
Bought	130-132 vt.	550-768 ton	4
Unrated	80 vt.	136 ton	1
Unknown	-	-	1
All	80-150 vt.	136-1210	43
BRITISH EAST INDIA COMPANY (EIC) VESSELS			
Ship Type	**Length**	**Tonnage**	**n**
Large	160-180 ft.	1200-1600 bm	11
Medium	125-170 ft.	700-1100 bm	22
Small	110-180 ft.	550-699 bm	30
Very small	100-115 ft.	200-549 bm	6
Unknown	-	-	11
All	100-180 ft.	200-1600 bm	80

Length and Tonnage

The length and **tonnage** of each ship were also examined. Descriptive statistics for the sample analyzed are shown in Table 6.

Table 6 Descriptive statistics for length and tonnage of British and Dutch vessels by company.

BRITISH VESSELS								
	Length (ft)				Tonnage (ton)			
Company of Ownership	***n***	***Mean***	***Median***	***SD***	***n***	***Mean***	***Median***	***SD***
British Naval Vessels	233	129.04	126	25.75	367	790.30	679	448.71
British Merchant Vessels (All)	37	150.85	146.17	18.15	69	787.04	690.48	290.13
East India Company (EIC)	37	150.85	146.17	18.15	69	787.04	690.48	290.13
Merchant Navy	0	-	-	-	0	-	-	-
Vessels of Unknown Company	0	-	-	-	0	-	-	-
Total British Vessels	270	132.03	132.25	25.93	436	789.79	679	427.28

DUTCH VESSELS								
	Length (vt)				Tonnage (ton)			
Company of Ownership	***n***	***Mean***	***Median***	***SD***	***n***	***Mean***	***Median***	***SD***
Dutch Naval Vessels	7	142.43	150	12.83	10	824	889	346.59
Dutch Merchant Vessels (All)	45	138.71	150	19.98	47	921.67	1150	312.22
Vereenigde Oost-Indische Compagnie (VOC)	41	142.29	150	12.78	42	965.86	1150	241.86
West-Indische Compagnie (WIC)	1	-	75	-	1	-	141.8	-
Middelburgsche Commercie Compagnie (MCC)	2	84.88	84.88	7.25	3	383.57	212	344.35
Merchant Marine & Private Merchant Vessels	1	-	163	-	1	-	1460	-
Vessels of Unknown Company	0	-	-	-	0	-	-	-
Total Dutch Vessels	52	139.2	150	19.12	57	904.54	898	317.47

British Naval Vessels

For British naval vessels, tonnage was frequently recorded in the CLIWOC database, but length less frequently so. For roughly half of the Royal Navy ships, data on ship type, length, and year built was manually added by the author, using the compendium *Ships of the Royal Navy* (Colledge and Warlow 2010). Historical documents indicate that the size of British naval vessels increased over time. The Establishments of 1745 provided set lengths for all rates of vessels, and these lengths were periodically increased, although there were no further sets of Establishments that laid out the dimensions for all rates (Creuze 1841, 20).

British Merchant Vessels

Lengths and tonnages of East India Company (EIC) ships were manually added using the compendiums *Catalogue of East India Company Ships' Journals and Logs, 1600-1834* (Farrington 1999) and *Ships of the East India Company* (Hackman 2001). Farrington listed both keel length and length of gundeck. Hackman notes in his introduction that the lengths he provided are the lengths between perpendiculars, but his measurements match those listed as keel length for Farrington. Because the records in Farrington were more complete, a preference was given for data from Farrington when possible. In addition, because a chaplain was required for all vessels of 500 or more tons, EIC ships were often registered at 498 or 499 tons despite being patently larger based on their construction dimensions (Hackman 2001)—this is evident in the CLIWOC database, and where available, the larger tonnages recorded in external sources were used.

Dutch Naval Vessels

Sample sizes for Dutch warships of known length or tonnage are small (n = 10 and 14, respectively) and are not evenly distributed over the period being analyzed. Accordingly, it was not possible to analyze length and tonnage for Dutch naval vessels.

Dutch Merchant Vessels

Lengths, tonnages, and crew sizes for many of the Dutch ships were provided in the database, mostly for VOC vessels. Tonnages were provided more often than lengths. Because VOC ships were built to set dimensions, it was possible in to extrapolate the length of the ship from the tonnage by using the contract dimensions provided in Bruijn, Gaastra, and Schöffer (1987, 37-52). Other dimensions for vessels were found in the De VOCsite online database (Overbeek 2015).

There were three rates of vessels, and the dimensions for all three of them were modified in 1742. It is worth noting that these establishments actually decreased the length of 1st and 2nd rate vessels compared to the earlier establishments (from 160 *voet* to 150 *voet* and from 145 *voet* to 136 *voet*, respectively), although they increased tonnage. In 1749, the length of 2nd rate vessels was increased from 136 to 140 feet. No further modifications were made to the dimensions after this.

Almost all of the 18th and 19th century vessels in the sample that were built by the VOC (as opposed to hired) were 1st or 2nd rate vessels built to established dimensions.

Only one ship, the 136 ton packet ship *Vlijt*, was not a rated vessel. The *Hercules*, built in 1743, is the only 2nd rate vessel in the database that was built to the 1742 standards. The remaining VOC vessels that are not of established dimensions were either hired or bought. The CLIWOC database also includes three VOC vessels from the 17th century. Lengths are available for two of them: the *Maarseveen*, built in 1660, and the *Afrika*, built in 1673. The *Afrika* was built to the established length of 160 feet, but the *Maarseveen* was one of a handful of vessels that were built 170 feet long.

WIC vessels, being engaged in the slave trade, tended to be on the small side—few were over 125 feet in length and fluyts were rarely used. Private traders participating in the slave trade within the markets that the WIC operated in were prohibited by statute from using fluyts or ships longer than 125 feet. This prohibition was dropped in 1762 (Postma 1990, 203-204).

Speed of Vessels

Day's Run

The database contains both the longitude and latitude recorded in the logbook each day at noon and the ship's estimation of the distance it had travelled since the previous noon, called the day's run. Since in the 18th and early 19th centuries longitude was calculated using the distance travelled each day, speed for this study was measured by using the day's run directly (rather than calculating it using the recorded longitude and latitude). The average speed (**average day's run**) for each ship was calculated by taking the sum of all days' runs and dividing it by the number of days the ship was in motion (had a distance travelled greater than 0). This allowed the exclusion of days spent in ports en route to the final destination or halted due to weather conditions, which is not accounted for in analyses that use only the number of days a ship spends traveling between two given ports. The **best day's run** (the day in the voyage where the ship travelled furthest in a 24 hour period) was also analyzed, as this represents the highest speed the ship achieved in real life conditions. This measurement was used by contemporaries to establish the reputation of ships. Although it is not possible to know a given ship's best day's run over its entire lifespan, as not all voyages it made are recorded in the database, the best day's run recorded in the database is still useful in comparing speed performance of ships.

Speed-Length Ratio

Speed-length ratio (abbreviated V/√L) is a measurement of speed which accounts for the fact that the most important factor in determining a vessel's maximum speed is the length of the vessel at the waterline. When a displacement hull (a hull which displaces water, rather than planes above the water surfaces) moves through the water, it produces pressure waves which travel from the bow to the stern along the length of the vessel. The faster the vessel moves, the longer the waves produced. The vessel reaches its maximum speed,[9] called the hull speed, when the wavelength of the pressure wave equals the length of the vessel (Reid 2017, 924). Because vessel length has such a

[9] Modern sailboats can be designed to exceed this maximum through planing above the surface of the water, and the 'bulbous bow,' developed in the middle of the 20th century, breaks up the bow wave on modern large ships, but hull speed is effectively the maximum for historical wooden sailing vessels.

significant effect on vessel speed, it is worth analyzing whether vessels improved in speed independent of length. The speed-length ratio allows us to do so, by comparing the speed of vessels accounting for length. It is calculated by taking the speed of the vessel in knots and dividing it by the square root of the length of the vessel at the water line.

For this analysis, the **average speed-length ratio** was calculated by taking the average day's run and dividing it by 24, to get a speed in knots, and then dividing it by the length of the vessel. The **maximum speed-length ratio** was calculated the same way, but using the best day's run instead. Descriptive statistics for British vessels can be found in Table 7, and those for Dutch vessels can be found in Table 8.

Table 7 Descriptive statistics for speed of British vessels by company. Average speed-length ratio was calculated using average day's run, and maximum speed-length ratio was calculated using best day's run.

	Average Day's Run				Average Speed-Length Ratio			
Company of Ownership	***n***	***Mean***	***Median***	***SD***	***n***	***Mean***	***Median***	***SD***
British Naval Vessels	383	94.05	92.42	19.54	233	0.3489	0.3451	0.0773
British Merchant Vessels (All)	74	101.05	100.62	13.31	37	0.3516	.03442	0.0454
East India Company (EIC)	73	100.96	100.39	13.38	37	0.3516	0.3442	0.0454
Merchant Navy	1	107.69	107.69	-	0	-	-	-
Vessels of Unknown Company	3	96.41	97.83	7.72	0	-	-	-
All British Vessels	460	95.19	94.53	18.78	270	0.3493	0.3451	0.0737

	Best Day's Run				Maximum Speed-Length Ratio			
Company of Ownership	***n***	***Mean***	***Median***	***SD***	***n***	***Mean***	***Median***	***SD***
British Naval Vessels	383	212.93	210	46.20	233	0.8035	0.7847	0.1756
British Merchant Vessels (All)	74	101.05	100.62	13.31	37	0.7302	0.7278	0.0970
East India Company (EIC)	73	208.90	207	29.27	37	0.7302	0.7278	0.0970
Merchant Navy	1	177	177	-	0	-	-	-
Vessels of Unknown Company	3	217	204	58.59	0	-	-	-
All British Vessels	460	212.24	209.5	43.94	270	0.7935	0.7733	0.1688

Table 8 Descriptive statistics for speed of Dutch vessels by company. Average speed-length ratio was calculated using average day's run, and maximum speed-length ratio was calculated using best day's run.

	Average Day's Run				**Average Speed-Length Ratio**			
Company of Ownership	***n***	***Mean***	***Median***	***SD***	***n***	***Mean***	***Median***	***SD***
Dutch Naval Vessels	131	96.25	93.26	21.91	7	0.3025	0.3212	0.0469
Dutch Merchant Vessels (All)	71	76.51	75.70	13.07	45	0.2763	0.2753	0.0402
Vereenigde Oost-Indische Compagnie (VOC)	42	77.29	79.36	10.23	41	0.2732	0.2733	0.0380
West-Indische Compagnie (WIC)	3	76.70	81.68	10.40	1	0.3134	0.3134	-
Middelburgsche Commercie Compagnie (MCC)	17	68.51	69.84	7.38	2	0.2736	0.2736	0.0545
Merchant Marine & Private Merchant Vessels	9	87.90	80.88	23.24	1	0.3702	0.3702	-
Vessels of Unknown Company	23	112.72	117.91	18.04	0	-	-	-
Total Dutch Vessels	225	91.70	87.39	22.24	52	0.2798	0.2756	0.0417

	Best Day's Run				**Maximum Speed-Length Ratio**			
Company of Ownership	***n***	***Mean***	***Median***	***SD***	***n***	***Mean***	***Median***	***SD***
Dutch Naval Vessels	131	212.72	209	43.02	7	0.6840	0.6668	0.1164
Dutch Merchant Vessels (All)	71	168.73	168	21.52	45	0.6041	0.5851	0.1057
Vereenigde Oost-Indische Compagnie (VOC)	42	166.55	167.5	20.01	41	0.5852	0.5819	0.0844
West-Indische Compagnie (WIC)	3	173.67	168	11.59	1	0.8997	0.8997	-
Middelburgsche Commercie Compagnie (MCC)	17	168.18	164	17.21	2	0.7817	0.7817	0.1614
Merchant Marine & Private Merchant Vessels	9	178.33	170	35.14	1	0.7378	0.7378	-
Vessels of Unknown Company	23	223.87	232	33.61	0	-	-	-
Total Dutch Vessels	225	199.98	192	42.34	52	0.6149	0.5918	0.1095

Units of Measure

All British ships recorded their speed in nautical miles (nm) per day. One nautical mile equals 1.85 kilometers (km). Dutch ships typically recorded in *duitse mijlen*, which equals four nautical miles or 7.41 kilometers (De Vooys, Dapper, and Van der Meer 2004). A few ships also recorded in leagues; one nautical mile equals three leagues. It was fairly easy to distinguish which unit was used where no unit was specified in the database. All measurements were converted to nautical miles for this analysis. A few ships were entered into the database as *duitse mijlen*, but the measurements were more in keeping with nautical miles, and were treated accordingly.

Length of ship was measured in feet and inches for British ships, and *voet* and *duim* for Dutch ships. Since the British foot equalled 0.30 m and the Dutch *voet* equalled 0.29 m (Carrington 1864, 3), the difference was judged to be unlikely to be significant, and no conversion was made.

Tonnages were recorded in "tons" for the British ships and in either "tons" or "lasts" for the Dutch. One last equals two Dutch tons (Lane 1964, 229). The diversity of meanings and ways of measuring tonnage are such that comparing tonnages between two countries is risky (Lane 1964), and no attempt to directly compare tonnages was made here.

Exclusions

Since the focus of this analysis was trends in shipbuilding methods and large scale patterns of shipping, ships with seven or less entries for the day's speed were excluded. The speed of vessels on very short voyages are more likely to be affected by factors other than those of interest (such as geography), and these entries were more likely to have a significant number of days in the voyage where no speed was available.

The three vessels from the Hudson Bay Company, which was sending out exploration expeditions in hopes of finding the Northwest Passage, and the seven Dutch whaling ships are of less interest to this analysis, as sample sizes are small and no lengths or tonnages are known for them. These vessels were accordingly excluded.

Due to the nature of manually entering data from hand written logs, it is not surprising to find a few entries that are likely erroneous. When obvious, ships with errors were excluded. All vessels that are listed as having recorded a day's run greater than 400 nm (740.8 km) are excluded, as this is faster than would be expected during this time. The Dutch naval vessel the *Princes Maria Louisa*, which has best day's run of 394 nm (729.7 km) recorded, was also excluded. Only a handful of 19th century wooden sailing ships achieved such speeds, all of which were American or British built clipper ships, neither of which are represented in this database. It is therefore safe to assume these are entry or unit of measurement errors. A handful of vessels with unlikely values for average day's run were also excluded. For example, the British naval vessel *Superb* has a recorded average day's run of 203 nm (376.0 km) while the six vessels of similar size averaged 113.6 nm (210.4 km).

In addition, two British Royal Navy vessels, the 38 ton sloop *Harrier* (built in 1804), and the 58 ton cutter *Spy* (purchased by the navy in 1763), were excluded from the analysis as they are dramatically smaller than the next smallest vessel, the 140 ton sloop *Cruizer*, and are therefore not representative of overall change in shipbuilding trends.

Methods

The primary hypothesis examined is that the speed of ships increases between 1730 and 1850; this is tested using multiple regression performed over the year the ship was built (ship year). All ship speed data was measured in the years 1750-1850. Because ship size has a substantial effect on ship speed, changes in length and tonnage will also be examined, with a secondary hypothesis being that ship size increases over time. Analysis of speed-length ratio is preferred to analysis of day's run because of this effect, but day's run will also be considered to test the primary hypothesis when speed-length is not available.

In order to meet the assumptions of linear and multiple regression, the normality of the independent variable was tested using a Shapiro-Wilks goodness-of-fit w-test. When necessary, data are transformed to achieve a distribution that is not skewed. For analyses where transformation is not discussed, the data was normally distributed and no transformation was necessary.

Regression models are chosen by considering linear and quadratic relationships between the independent variable and the ship year. Possible models are evaluated by reducing the model until all terms have a significant p-value (alpha = 0.05) and/or by using stepwise analysis to minimize AICc and BIC. Where methods disagree, simpler models are preferred unless the more complex model produces a significant improvement in adjusted R-square. The following models are considered for each regression, where ‘a’ is an additional explanatory variable, being nationality, company, or ship type, depending on the analysis in question. The intercept is represented as 'Int'.

$$y = Int + ShipYear$$

$$y = Int + a + ShipYear$$

$$y = Int + a + ShipYear + a*ShipYear$$

$$y = Int + a + ShipYear + ShipYear^2$$

$$y = Int + a + ShipYear + a*ShipYear + ShipYear^2 + a*ShipYear^2$$

When comparing two groups directly without the variable ship year, a two-tailed t-test is performed to check for differences between groups.

CHAPTER IV

ANALYSIS

Factors by Company

British Royal Navy

Technical Change

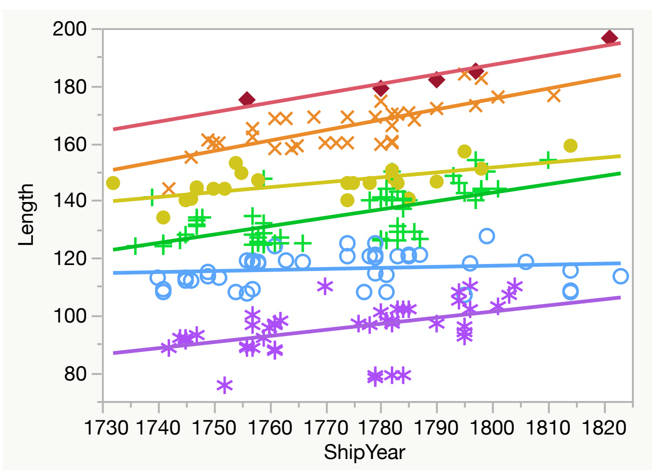
A linear regression of the length and tonnage of all British Royal Navy vessels is shown in Table 9. On average, British Royal Navy (RN) ships built in 1830 were 25.3 feet longer and 308.95 bm larger than those built in 1730. However, these models do a poor job of capturing the variability of the data.

Table 9 Linear regression of length and tonnage for all British naval vessels. Analysis includes transports and ships of unknown type. Length is measured in feet (ft) and tonnage in tons burthen (bm).

Length	
Prediction Equation	y = -319.8319 + 0.2533*ShipYear
n	233
σ	25.32
Adj R^2	0.0326
p-value	0.0033*
Tonnage	
Prediction Equation	y = -5645.7870 + 3.6286*ShipYear
n	367
σ	443.65
Adj R^2	0.0225
p-value	0.0023*

Including the rating of the ship (ship type) as a dependent variable accounts for most of this variation. The best model for length is shown in Figure 2. The increase in length over time is significant for 2nd, 3rd, 4th, and 5th rate ships and Unrated vessels (Table 10), although sample size for 2nd rate vessels is very small (n=5). There was no significant change in length for 6th rate vessels, and there are no 1st rate vessels in the database.

Figure 2 Regression of length over time by ship type (rating) for the British Royal Navy. Length is measured in feet. Transports and ships of unknown type were excluded from this analysis. Prediction equations are shown in Table 10.



n	225
σ	6.02
Adj R^2	0.9442

Effect	**P-value**
ShipYear	<0.0001*
ShipType	<0.0001*
ShipYear*ShipType	<0.0001*

Key

◆ 2nd Rate   + 5th Rate

× 3rd Rate   ○ 6th Rate

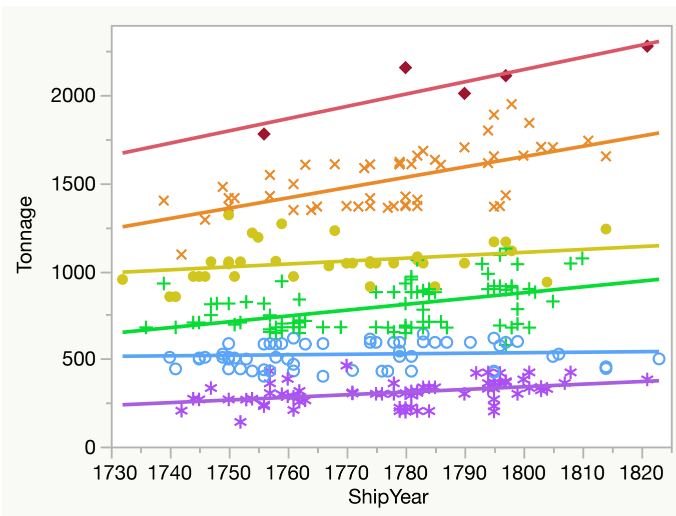
● 4th Rate   ✳ Unrated

Table 10 Prediction equations for the length over time of British Royal Navy vessels by ship type (rating). Length is measured in feet. Transports and ships of unknown type were excluded from this analysis. The model is shown in Figure 2.

Ship Type	***n***	***Prediction Equation for Length***	***p-value ShipYear***
2nd Rate	5	y = -408.4927 +0.3309*ShipYear	0.0324*
3rd Rate	34	y = -2522.7674 + 1.5168*ShipYear	<0.0001*
4th Rate	25	y = -158.7917 + 0.1723*ShipYear	0.0008*
5th Rate	63	y = -384.1090 + 0.2926*ShipYear	<0.0001*
6th Rate	50	y = 50.8415 + 0.0368*ShipYear	0.3187
Unrated	48	y = -282.6409 + 0.2132*ShipYear	0.0006*

Including ship type as a variable when analyzing tonnage produces the model shown in Figure 3. The changes in tonnage over the period from 1730 to 1830 are shown in Table 11. The increase in tonnage is significant for all rates except 5th rates.

Figure 3 Regression of tonnage over time by ship type (rating) for the British Royal Navy. Tonnage is measured in tons burthen (bm). Transports and ships of unknown type were excluded from this analysis. Prediction equations are shown in Table 11.



n	348
σ	98.51
Adj R^2	0.9499

Effect	**P-value**
ShipYear	<0.0001*
ShipType	<0.0001*
ShipYear*ShipType	<0.0001*

Key

- ◆ 2nd Rate
- × 3rd Rate
- ● 4th Rate
- + 5th Rate
- ○ 6th Rate
- ✳ Unrated

Table 11 Prediction equations for the tonnage over time by ship type (rating) for the British Royal Navy. Length is measured in feet. Transports and ships of unknown type were excluded from this analysis. The model is shown in Figure 3.

Ship Type	***n***	***Prediction Equation for Tonnage***	***p-value ShipYear***
2nd Rate	5	y = -3838.3146 + 6.983*ShipYear	0.034*
3rd Rate	34	y = -4304.393 + 5.8699*ShipYear	0.0005*
4th Rate	25	y = -4737.6077 + 1.6557*ShipYear	0.0361*
5th Rate	63	y = -5011.1262 + 3.3127*ShipYear	0.943
6th Rate	50	y = -5272.7596 + 0.2939*ShipYear	<.0001*
Unrated	48	y = -4777.178 + 3.2697*ShipYear	<.0001*

Speed Over Time

British Royal Navy ships built in 1830 travelled faster than ships built in 1730. The increase in overall average day's run is best modeled with a quadratic equation, shown in Table 12. This increased from 94.93 nm (175.81 km) per day for ships built in 1730 to 120.92 nm (223.95 km) for ships built in 1830. The increase in the best recorded day's run for each ship in the database is best modeled with a linear equation, also shown in Table 12. Ships built in 1730 have an average best day's run of 200.89 nm (372.05 km) and those built in 1830 an average of 228.45 nm (423.09 km).

Table 12 Regression of average day's run and best day's run for all British Royal Navy vessels. Analysis includes transports and ships of unknown type. Day's run is measured in nautical miles (nm).

Average Day's Run	
Prediction Equation	y = -236.8889 + 0.1853*ShipYear + 0.0059*(ShipYear-1773.65)^2
n	383
σ	10.06
Adj R^2	0.0488
p-value ShipYear	0.0033
p-value ShipYear^2	0.0176*
Best Day's Run	
Prediction Equation	y = -275.89 + 0.28*ShipYear
n	383
σ	443.65
Adj R^2	0.0109
p-value	0.0228*

Since length increased over time, the analysis was also done using speed-length ratios. There was no statistically significant increase in max speed-length ratio (p-value = 0.2876). The model Avg Speed-Length Ratio = Int + ShipYear + ShipType shows a statistically significant improvement over time, with slope 0.0005 and p-value = 0.0288. However, when each ship type is looked at by itself, only the 2nd and 3rd rate vessels show an improvement in either average or max speed-length ratio. The sample size for 2nd rate vessels (n=5) is too small to give the results much weight. The model for the increase for 3rd rate vessels is shown in Table 13. The increase in average speed-length ratio is over the century is 0.17, which indicates that a ship built in 1830 at 165 feet long (the mean length for 3rd rate vessels in the database) traveled 50.52 nm (93.56 km) further per day than one of the same size built in 1730. The average increase in max speed-length ratio is 0.24, which means a 165-foot-long ship built in 1830 traveled 73.32 nm (135.79 km) further per day than one of the same length built in 1730.

Table 13 Regression of average speed-length ratio and maximum speed-length ratio for British Royal Navy 3rd Rate vessels.

Average Speed-Length Ratio	
Prediction Equation	y = -2.606 + 0.002*ShipYear
n	34
σ	0.04
Adj R^2	0.2758
p-value ShipYear	0.0008*
Maximum Speed-Length Ratio	
Prediction Equation	y = -275.89 + 0.28*ShipYear
n	383
σ	443.65
Adj R^2	0.0109
p-value	0.0228*

EIC

Technical Change

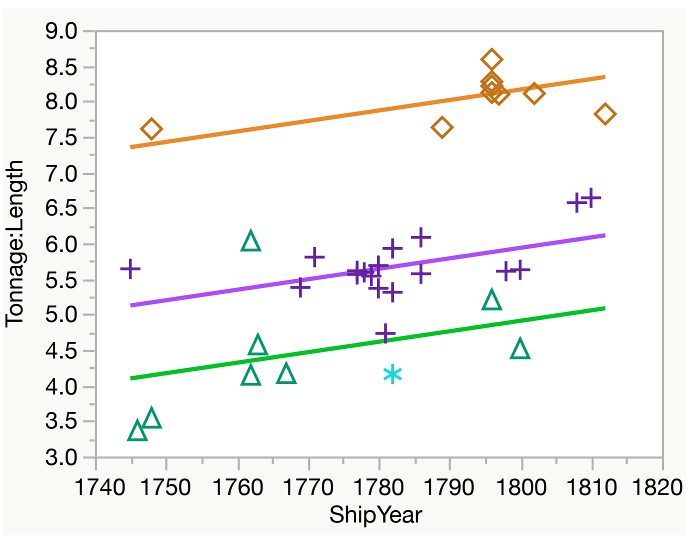
In terms of technical change over time, East India Company (EIC) ships show a different pattern than British Royal Navy ships. Length does not show any statistically significant trend over time (p-value 0.8530). However, tonnage does increase significantly over time, indicating increased breadth and/or depth (Table 14). In order to achieve a normal distribution of the residuals, this analysis was performed on the natural log of tonnage. Tonnage increases over time, with ships gaining on average 7.02 tons burthen per year. The average tonnage in 1730 is 860.06 bm, and the average tonnage in 1830 is 2115.40 bm, for a total increase of 1255.34 bm. The increase is significant with p-value <0.0001.

Table 14 Regression of the natural log of tonnage over time for the EIC vessels.

	Tonnage
Prediction Equation	y = exp(-8.8126 + 0.0087*ShipYear)
n	69
σ	0.29
Adj R^2	0.3340
p-value	<0.0001*

Perhaps more significantly, the tonnage to length ratio increases over time. This trend is especially clearly seen when the size categories (ship type) are included in the analysis (Figure 4, p-value < 0.0001). The single vessel of known length in the very small category (less than 550 tons) was excluded from this analysis, although it is shown on the graph. The prediction equation for the tonnage to length ratio for each size category is shown in Table 15, along with the predicted average for each. The mean length for all EIC ships was 150 ft. If a ship of that length had been built in 1730, would have been on average 723.29 tons burthen, but one of the same length built in 1830 would have been on average 943.79 tons burthen, a difference of 220.50 bm. Or, put another way, a ship of 850 tons burthen (mean tonnage) built in 1730 would have been on average 163.21 ft long, while one of the same tonnage built in 1830 would have been on average only 125.08 ft long, or 38.13 ft shorter.

Figure 4 Regression of tonnage to length ratio over time by ship type for the EIC. Ship type represents an artificial category similar to the rating used by the VOC. The single ship in the 'very small' category shown on the graph is not included in the analysis.



n	35
σ	0.49
Adj R^2	0.8826

Effect	**P-value**
ShipYear	0.0069*
ShipType	<0.0001*

Key
- ◇ Large
- + Medium
- △ Small
- ∗ Very Small

Table 15 Prediction equations for tonnage to length ratio by ship type for the EIC. Ship type represents an artificial category similar to the rating used by the VOC.

Prediction Equation				
Ship Type	***Prediction Equation***			
Large	y = -18.3813 + 0.0147*ShipYear			
Medium	y = -20.6091 + 0.0147*ShipYear			
Small	y = -21.6357 + 0.0147*ShipYear			
Tonnage Predicted by Length				
Ship Type	***Mean Length***	***Predicted Tons 1730***	***Predicted Tons 1830***	***Predicted Difference***
Large	173 ft	1219.60 bm	1473.91 bm	254.31 bm
Medium	143 ft	689.53 bm	899.74 bm	210.21 bm
Small	150 ft	569.30 bm	789.80 bm	220.50 bm
Length Predicted by Tonnage				
Ship Type	***Mean Tonnage***	***Predicted Length 1730***	***Predicted Length 1830***	***Predicted Difference***
Large	1378 bm	195.47 ft	161.74 ft	-33.73 ft
Medium	808 bm	167.57 ft	128.42 ft	-39.15 ft
Small	631 bm	166.26 ft	119.84 ft	-46.42 ft

Speed Over Time

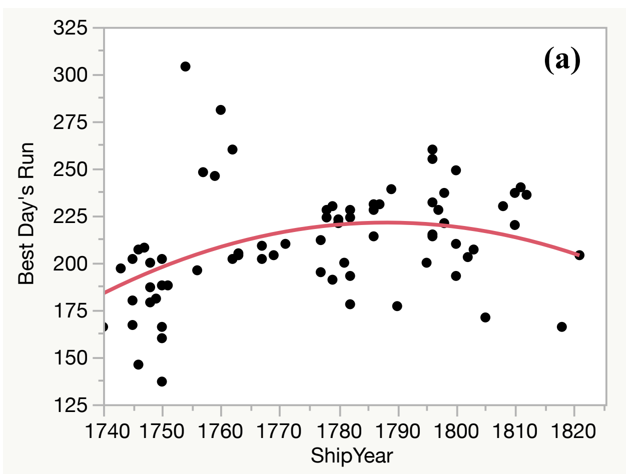
British merchant ships gain in speed over time (Table 16). Ships built in 1740 had mean average day's run of 91.06 nm (168.64 km) and those built in 1820 had a mean of 114.31 nm (211.70 km), which is an increase of 26.16 nm (48.45 km). Extrapolating out to the 1730 to 1830 time span that was used for the analysis of British Royal Navy vessels, for comparison, gives an increase of 29.07 nm (53.84 km) in average day's run. This model includes four ships of unknown company, two of which are listed as packet boats, and one ship attributed to the company "merchant navy."

Table 16 Regression of average day's run for all British merchant vessels. This includes all EIC vessels, one "merchant navy" vessel and three vessels of unknown company.

	Average Day's Run
Prediction Equation	y = -414.7611 + 0.2907*ShipYear
n	77
σ	11.22
Adj R^2	0.2700
p-value	<0.0001*

A quadratic model for best day's run is shown in Figure 5(a). The quadratic term is significant due to the influence of the two packet boats, shown as stars in Figure 5(b). Although neither tonnage nor length are available for these vessels, they are almost certainly smaller than the East Indiamen that make up most of the sample (estimated mean tonnage for EIC ships in 1813, the last year there are entries for the company, is 1,815.29 tons); such ships were not built to carry large volumes of cargo. Because of this size difference, it is not convincingly demonstrated that British merchant ships' best day's runs decreased towards the end of the time period, as shown in the model. Excluding these points produces a linear model (Figure 5(b)). This model estimates the mean best day's run at 190.36 nm (352.55 km) in 1740 and at 235.31 nm (435.79 km) in 1820, which is an increase of 50.56 nm (93.64 km). Extrapolating out to 1830 produces a difference of 56.18 nm (104.05 km).

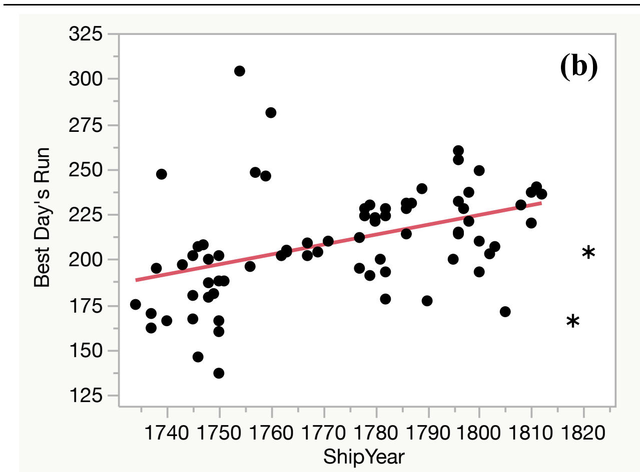
Figure 5(a) and 5(b) Regression of best day's run for all British merchant vessels. This includes all EIC vessels, one "merchant navy" vessel and three vessels of unknown company. The two vessels shown as stars in (b) are packetboats of unknown company, and are significantly smaller than the EIC ships of the same time period. They were excluded in (b).



n	77
σ	27.60
Adj R^2	0.1700
Effect	**P-value**
ShipYear	0.0007*
ShipType	0.0131*

Prediction Equation

$y = -785.6348 + 0.5640*ShipYear - 0.0102*(ShipYear-1772.62)^2$



n	77
σ	27.75
Adj R^2	0.1604
Effect	**P-value**
ShipYear	0.0002*

Prediction Equation

$y = -787.1702 + 0.5618*ShipYear$

Key

∗ Packetboat (excluded)

Average speed-length ratio also increases over time for the EIC ships (Table 17). Values are available for from 1740 to 1815. In that time, the average speed-length ratio increases from 0.2389 to 0.3615. Converted back into day's run, this indicates a 150-foot-long ship built in 1740 traveled on average 70.23 nm (130.07 km) per day, and one of the same length built in 1820 traveled on average 106.27 nm (196.81 km) per day. There is one notable outlier, the *Marlborough*, built in 1746, but the slope remains significant if it is excluded from the analysis (p = 0.0033, slope = 0.0010).

Maximum speed-length ratio also increases (Table 17). On average, the maximum speed-length ratio increases by 0.2091, from 0.5772 to 0.7863. This indicates a 150-foot-long ship built in 1740 would have a best day's run of 215.28 nm (398.70 km) while one built in 1820 would have one of 269.37 nm (498.87 km). There is one noticeable outlier, *Admiral Pocock,* built in 1762. If excluded, the slope increases to 0.0028 per year, with a p-value <0.0001.

Table 17 Regressions of average and maximum speed-length ratios for EIC vessels of known length.

Average Speed-Length Ratio	
Prediction Equation	y = -2.0194 + 0.0013*ShipYear
n	37
σ	0.0385
Adj R^2	0.2873
p-value ShipYear	0.0004*
Maximum Speed-Length Ratio	
Prediction Equation	y = -3.2696 + 0.0023*ShipYear
n	37
σ	0.0886
Adj R^2	0.1656
p-value	0.0072*

Dutch Navy

Technical Change

The CLIWOC database does not contain sufficient information on Dutch naval vessels to be able to track changes in tonnage or length. Sample sizes for vessels of known tonnage (n=14) and length (n=10) were too small and dated mostly from the first half of the period.

Speed Over Time

A quadratic model best fit the average day's run (Table 18). It was necessary to transform the data by squaring the independent variable, as the residuals skewed left. The average of the average day's runs for Dutch naval vessels built in 1745 was 78.15 nm (144.73 km); in 1850 it was 122.1 nm (226.13 km), a gain of 43.99 nm (81.47 km).

For the best day's run, a quadratic model is also appropriate. A natural log transformation is necessary to achieve normally distributed residuals. This model is also shown in Table 18. The average best day's run in 1745 was 192.44 nm (356.40 km), while the average in 1850 was 250.99 nm (464.83 km), a gain of 58.55 nm (108.43 km).

Speed-length ratio could not be analyzed for Dutch naval vessels due to the lack of available length measurements.

Table 18 Regression of average and best day's run for Dutch naval vessels. To achieve normally distributed residuals, average day's run was transformed to the second power and a natural log transformation was performed on best day's run.

Average Day's Run	
Prediction Equation	
$y = \sqrt{-179502.8 + 104.2763 * \text{ShipYear} + 1.0902 * (\text{ShipYear} - 1806.58)^2}$	
n	131
σ	3374.73
Adj R^2	0.4075
p-value ShipYear	<0.0001*
p-value $(\text{ShipYear-1806.58})^2$	0.0036*

Best Day's Run	
Prediction Equation	
$y = \exp(-0.5945 + 0.0033*\text{ShipYear} + (4.058*10^{-5})*(\text{ShipYear-1806.58})^2)$	
n	131
σ	0.17
Adj R^2	0.2014
p-value ShipYear	<0.0001*
p-value $(\text{ShipYear-1806.58})^2$	0.0322*

Dutch Merchants

Technical Change

There is no statistically significant change in length for *Verenigde Oost-Indische Compagnie* (Dutch East India Company, VOC) vessels built over the period 1740-1800 (p-value = 0.0709). There is a statistically significant change in tonnage (p-value = 0.0507), but this is due entirely to the presence of the only unrated vessel, the *Vlijt,* at the end of the period. Excluding the *Vlijt*, the p-values become 0.1120 for tonnage and 0.1259 for length.

In addition to the VOC ships, the CLIWOC database included the lengths of three *West-Indische Compagnie* (West India Company, WIC) ships and one

Middelburgsche Commercie Compagnie (Middleburg Commercial Company, MCC) vessel built in the period 1750-1800, but these sample sizes are too small to draw conclusions about the ships of these companies Including these in an analysis with the VOC ships produces p-values of 0.1143 for length and 0.3873 for tonnage.

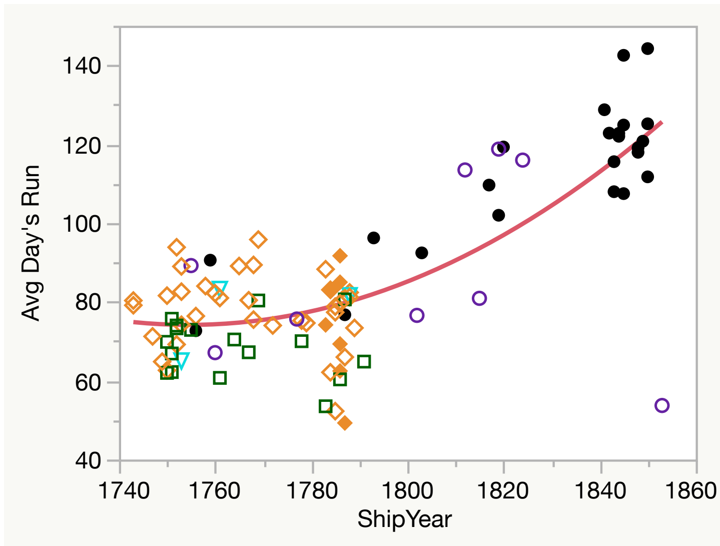
Speed Over Time

Looking at the day's run data of all Dutch merchant ships, a very distinctive pattern emerges (Figure 6 and 7). Looking at the period from 1745 to 1800 alone, there is no statistically significant change in average day's runs (p-value = 0.9390) or best day's runs (p-value = 0.2196).

After 1800, however, a dramatic increase in ship speed is evident. A ship built in 1745 traveled on average 81.20 nm (150.38 km) in a day, and make a best day's run of 192.44 nm (356.40 km). One built in 1850, however, averaged 124.35 nm (230.30 km) per day, and made a best day's run of 250.99 nm (464.83 km). This is a gain of 43.15 nm (79.91 km) in average day's run, and 58.55 nm (108.43 km) in best day's run.

As there is only a single vessel of known length in the second half of the time period, it is only possible to analyze speed-length ratio for vessels built before 1800. All of these vessels are company-owned, as there are no lengths currently available for 18th century privately-owned ships. For VOC vessels in this period, there is no statistically significant change in average speed-length ratio over time (p-value = 0.8784) or for maximum speed-length ratio (p-value = 0.5891).

Figure 6 Regression of average day's run for all Dutch merchant vessels.



n 94
σ 13.73
Adj R^2 0.5818

Effect	**P-value**
ShipYear	<0.0001*
ShipYear^2	0.0005*

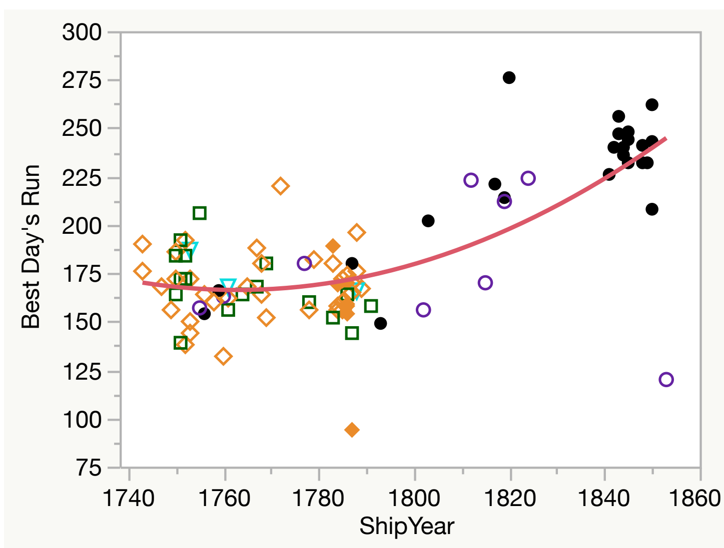
Prediction Equation

$y = -527.4869 + 0.3398*\text{ShipYear} + 0.0053*(\text{ShipYear}-1786.52)^2$

Key

VOC (built) MCC
VOC (hired) Private merchant
WIC Unknown

Figure 7 Regression of best day's run for all Dutch merchant vessels.



n 94
σ 24.23
Adj R^2 0.5038

Effect	**P-value**
ShipYear	<0.0001*
ShipYear^2	0.0003*

Prediction Equation

$y = -645.3373 + 0.4573*\text{ShipYear} + 0.0097*(\text{ShipYear}-1786.52)^2$

Key

VOC (built) MCC
VOC (hired) Private merchant
WIC Unknown

Comparing vessels that the VOC hired or purchased to the vessels they built using a two-sided t-test shows no statistically significant difference in the average speed-length ratio (p-value = 0.5892) or the maximum speed-length ratio (p-value = 0.7790).

Likewise the difference between the vessels built in the 18th century and those built in the 17th century show no significant difference, with the p-value for the average speed-length ratio at 0.2555 and for the maximum speed-length ratio at 0.6860, although with a sample size of only two for the 17th century, too much weight should not be placed on these results. Sample sizes from the other companies are too small to draw conclusions, although including them in the speed-length ratio analysis did not produce a significant change in speed-length ratio over time.

Comparison between Companies

All Vessels

A comparison of the average day's run of all vessels in the sample can be seen in Figure 8, which shows the regressions described in the earlier sections superimposed on each other. A linear regression is used for the British merchant vessels, and quadratic regressions are used for the other categories. British merchant, British navy, and Dutch merchant ship speeds converge on each other near the end of the regression, although Dutch naval vessels lag behind.

Figure 9 shows the regressions for the best day's runs. British vessels were modeled with linear regressions, and Dutch vessels with quadratic regressions. There is no difference between British merchant and British naval vessels (p-value = 0.7272), although both show a statistically

Figure 8 Overlay of the regressions of average day's run for each category of vessel—British Royal Navy (Table 12), British merchant (Table 16), Dutch navy (Table 18), and Dutch merchant vessels (Figure 6)—for the period from 1740 to 1825. Prediction equations and statistics can be found in those figures and tables.

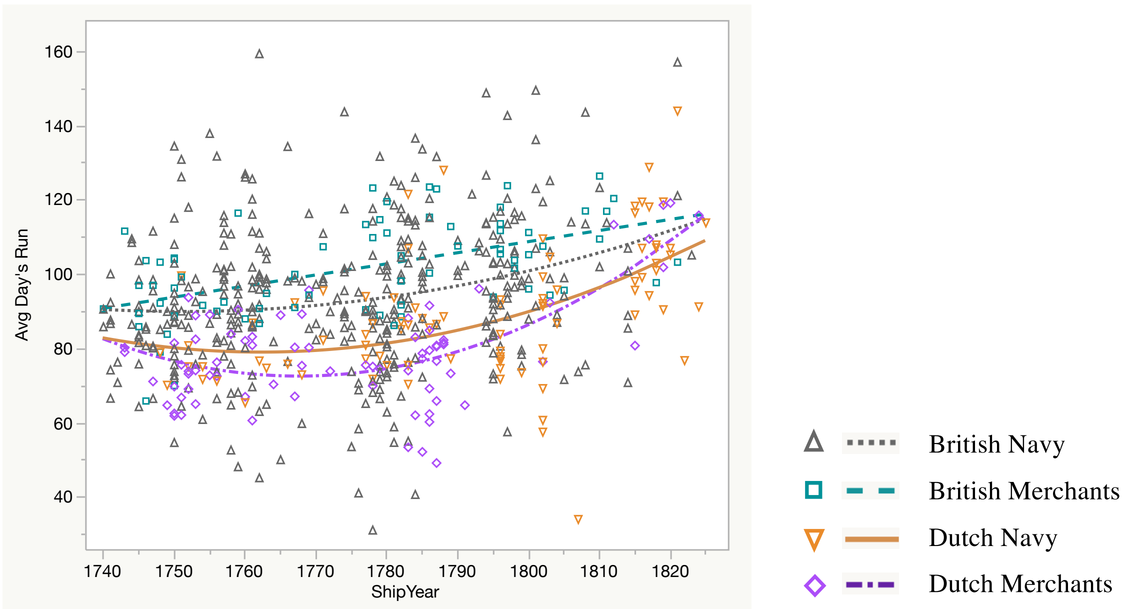
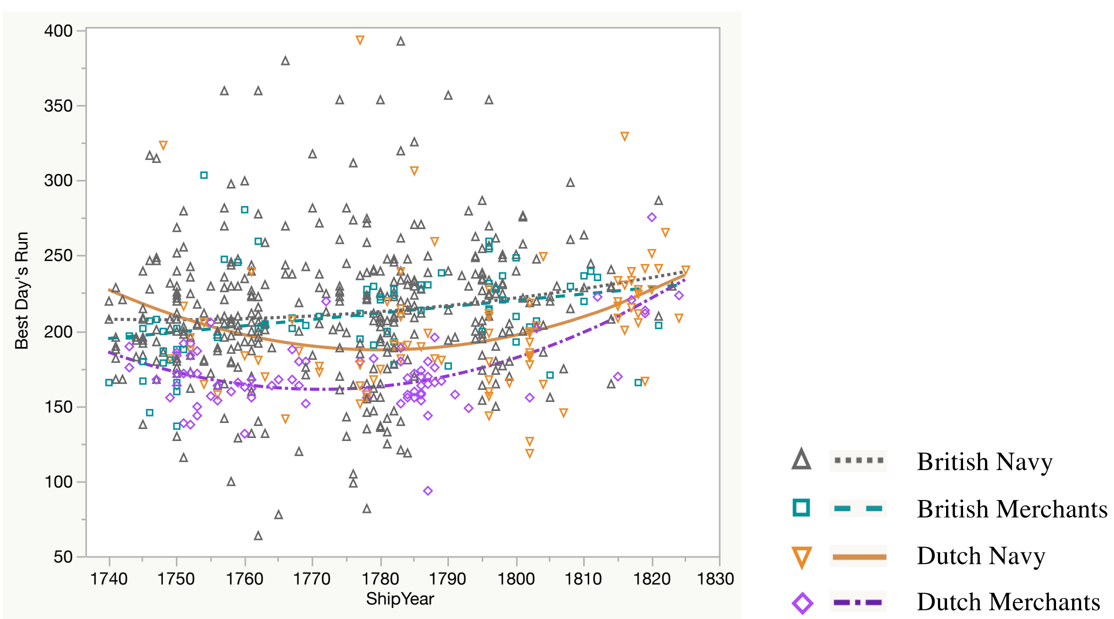


Figure 9 Overlay of the regressions of best day's run for each category of vessel—British Royal Navy (Table 12), British merchant (Table 5(b)), Dutch navy (Table 18), and Dutch merchant vessels (Figure 7) —for the period from 1740 to 1825. Prediction equations and statistics can be found in those figures and tables.



significant increase in speed over time. Dutch merchant vessels also show a significant increase over time. Dutch naval vessels, however, do not. Both the starting mean best day's run and the ending mean best day's run are visibly close to the British values.

Naval Vessels

We can also compare the two navies directly. This comparison is shown in Table 19. The British naval vessels have average day's run 5.48 nm (10.15 km) higher and best day's runs 10.07 nm (18.65 km) higher than the Dutch naval vessels.

Table 19 Regression of average day’s run and best day’s run by nationality for British and Dutch naval vessels.

Average Day’s Run	
Prediction Equation	
British	$y = -354.1229 + 0.2513*ShipYear + 0.006*ShipYear^2$
Dutch	$y = -359.7021 + 0.2513*ShipYear + 0.006*ShipYear^2$
n	455
σ	18.46
Adj R^2	0.0913
p-value	
Nationality	<0.0001*
ShipYear	<0.0001*
$ShipYear^2$	0.0024*
Best Day’s Run	
Prediction Equation	
British	$y = -363.4817 + 0.3225*ShipYear + 0.0123*ShipYear^2$
Dutch	$y = -376.5245 + 0.3225*ShipYear + 0.0123*ShipYear^2$
n	455
σ	45.23
Adj R^2	0.0393
p-value	
Nationality	0.0006*
ShipYear	0.0123*
$ShipYear^2$	0.0167*

Some Dutch naval vessels do list a ship type, although the only type with a sample size that is represented across a long enough period for comparison is the *fregats* (frigates). These can be compared to a 5th rate British naval vessel, which are represented in the database for the period from about 1730 to 1815. No statistically significant change is observed in average day's run for either nationality over that time period (p-value = 0.1666) or in best day's run (p-value = 0.4532). A two-sided t-test reveals no difference between the nationalities (p-value = 0.0778).

Merchant Vessels

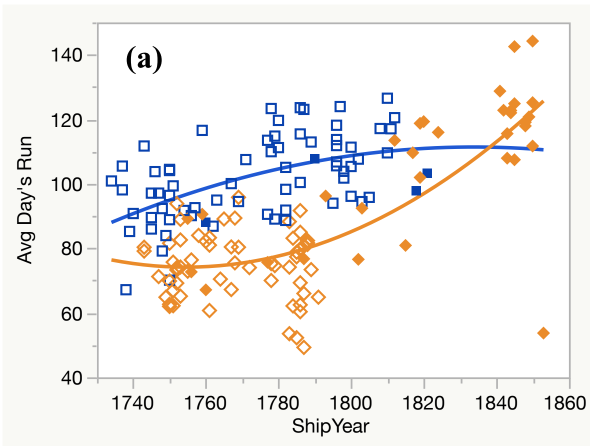
Data are available for British merchant vessels built between about 1740 and 1821, all but four of which are from EIC ships. Data for Dutch merchant vessels is available from 1741 to 1850. The regression analysis for the average day's run and best day's run for the two categories from the period from 1741 to 1821 is shown in Table 20.

To estimate when Dutch merchant vessels match British merchant vessels in speed, a regression can be run for the period 1740-1850. This produces the result shown in Figure 10(a). In this model, Dutch merchant ships overtake the speed of British merchant ships in 1839. The three points marked as stars in Figure 10(b) had disproportionate impact on the regression lines. The British ships, which are the two packet boats discussed in the British Merchant section above, produce a noticeable downward bend in the line, although the quadratic term is not significant for the British data alone (p-value = 0.2922). The Dutch outlier influences the Dutch line downward. These three points were excluded in the model shown in Figure 10(b). This model

Table 20 Comparison of average day's run and best day's run over time by nationality for British and Dutch merchant ships.

Average Day's Run	
Prediction Equation	
British	y = -341.073169 + 0.2500*ShipYear + 0.061*(ShipYear-1774.89) -0.0031*$(\text{ShipYear-1774.89})^2$
Dutch	y = -355.8035 + 0.2500*ShipYear + 0.0050*$(\text{ShipYear-1774.89})^2$
n	144
σ	10.77
Adj R^2	0.6333
p-value	
Nationality	<0.0001*
ShipYear	<0.0001*
ShipYear^2	.0209*
Nationality*ShipYear	0.2997
Nationality*ShipYear^2	<0.0001*
Best Day's Run	
Prediction Equation	
British	-390.568011 + 0.3436*ShipYear + 0.1563*(ShipYear-1774.89) - 0.0196*$(\text{ShipYear-1774.89})^2$
Dutch	-419.6619 + 0.3436*ShipYear + 0.0032*$(\text{ShipYear-1774.89})^2$
n	144
σ	23.78
Adj R^2	0.4879
p-value	
Nationality	<0.0001*
ShipYear	0.0004*
ShipYear^2	0.4623
Nationality*ShipYear	0.1041
Nationality*ShipYear^2	<0.0001*

Figure 10(a) and 10(b) Prediction of the point of intersection between the regressions of British and Dutch merchant vessels' average day's run. Vessels marked as stars in (b) were excluded from that analysis. The two British vessels are packetboats and are significantly smaller than the other British vessels included, which are mostly EIC ships.

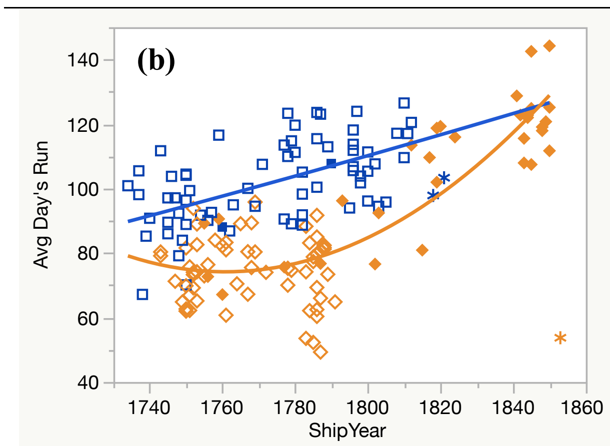


n	166	
σ	12.5952	
Adj R^2	0.5952	

Parameter	**Estimate**	**p-value**
Intercept	-381.4888	<0.0001*
ShipYear	0.2655	<0.0001*
Nationality	13.4812	<0.0001*
Nationality*ShipYear	-0.0193	0.6840
$ShipYear^2$	0.0015	0.3622
$Nationality*ShipYear^2$	-0.0038	0.0196*

Key

◆ Dutch merchant (private or unknown company)
◇ Dutch merchant (company owned)
■ British merchant (private or unknown company)
□ British merchant (company owned)



n	163	
σ	11.0667	
Adj R^2	0.6834	

Parameter	**Estimate**	**p-value**
Intercept	-381.4888	<0.0001*
ShipYear	0.2655	<0.0001*
Nationality	13.4812	<0.0001*
Nationality*ShipYear	-0.0193	0.6840
$ShipYear^2$	0.0015	0.3622
$Nationality*ShipYear^2$	-0.0038	0.0196*

estimates the point of intersection at 1848. The point of intersection from modeling the best day's run (Table GA) puts the point of intersection at 1820, whether the outliers are included or not. We can thus estimate that Dutch merchant ships matched British merchant ships in speed sometime between 1820 and 1848, but more likely towards the end of that period.

CHAPTER V

CONCLUSIONS

Technical improvement in the construction of British Royal Navy vessels is evident in the data. Length and tonnage increase for 2nd, 3rd, 4th, and 5th rate ships, as well as for unrated vessels. The absence of increase in length or tonnage among 6th rate vessels, however, is notable. Given this increase in size, it is not surprising to find a significant increase in speed as well. Ships built in 1830 travelled, on average, 26 nm (48 km) further per day than ones built in 1730, an increase of 27 percent. They also achieved best day's runs almost 28 nm (51 km) higher than their earlier counterparts, an increase of 28 percent. For all vessels smaller than 3rd rate vessels, however, there is no increase in average or maximum speed-length ratios. This suggests that the gain in speed is largely due to the increase in length. British naval shipwrights were either satisfied with the increase in speed due to length or other needs took priority for these vessels.

2nd and 3rd rate vessels, however, do gain in speed beyond the gain to be expected by their length, although sample sizes for 2nd rate vessels are too small to be confident in the results (n=5). The average speed-length ratio of 3rd rate vessels increases by 0.12, an increase of 51 percent, and the max speed-length ratio increases by 0.21, an increase of 36 percent. It is not possible to tell why these differ from the smaller vessels. One possible reason is that the improvement is due to rigging, which may have had a greater effect in larger vessels that could carry more sail. Alternately, 3rd rate ships may have achieved a length-breadth ratio more suited to speed than other ratings. Nor is it possible at this time to estimate how much of this increase is due to the introduction of copper plating.

The British merchant ships included in the analysis are largely East India Company ships. They do not show a gain in length over time, but they do show a gain in tonnage and length to tonnage ratio. Cargo capacity was highly important to the East India trade, and the increase in tonnage is evidence that shipbuilders' ability to meet this need improved with time. Despite the lack of gain in the length of the vessels, merchant ships do gain in speed over time, whether measured by day's run or speed-length ratio. The gains over the period from 1740 to 1820 are quite large. Average day's run improved by 23 nm (43 km), a gain of 26 percent, and best day's run by 45 nm (83 km),[10] a gain of 24 percent. This indicates that speed in shipping was a factor sought by merchants during the late 18th and early 19th centuries. This is clear evidence of an improvement in ship speed beyond gains in length.

Technical improvements in Dutch naval vessels cannot be analyzed, but they show a noticeable increase in ship speed. They gain 44 nm (81 km) in average day's run over the period from 1745 to 1850, or 53 percent. In best day's run, they gain 59 nm (108 km), or 30 percent. The pronounced quadratic effect observed in the data may be due to increasing size of ships towards the latter half of the period. Glete (2000) notes that the Dutch naval yards in the 18th century concentrated on producing two-deckers of 40 to 56 guns. During the Fourth Anglo-Dutch War, naval yards were ordered to build 75 ships-

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[10] Using the linear model produced by excluding the two packet boats

of-the-line, in addition to 35 more frigates, but problems of disorganization, corruption, and lack of access to seasoned wood plagued the construction program. Still a number of large warships were successfully launched. The establishment of the Batavian Republic in 1795 brought the disparate admiralties of the different Dutch provinces under a centralized administration, and the French used the Dutch dockyards to produce a significant amount of tonnage during the Napoleonic Wars. Dutch shipbuilders may also have adapted or been influenced by French designs during this time period.

Overall, Dutch naval speed is statistically slower than British naval vessels for the same period, lagging behind by 5 nm (10 km) in average day's run and 10 nm (19 km) in best day's run. It should be noted that the Dutch sample is much smaller than the British one, being only 76 vessels compared to 366. Because differences in size of vessels between the Dutch and the British sample cannot be accounted for, it is not possible to tell if this is actually due to differences in quality of ship design. If less ships-of-the-line are included in the Dutch data relative to the British, differences would be expected simply from the effect that length and sail area have on speed. A comparison of Dutch ships that are known to be frigates with British 5th rate vessels over the period from 1730 to 1815 produces no statistically significant differences in average or maximum day's run. This indicates that Dutch shipwrights were able to build ships capable of matching their British counterparts in speed, in contrast to the reputation historians such as Glete (2000) ascribe to them.

Dutch merchants show perhaps the most pronounced pattern. Dutch merchants show no increase in average day's run prior to 1800. With the collapse of the Dutch merchant companies at the end of the 18th century, Dutch merchant vessels show rapid increases in day's run. The VOC built all ships to tightly controlled, standardized establishments that did not change at all over the second half of the 18th century. The results of that are clearly seen in the lack of any gain in ship speed over this period. During the Fourth Anglo-Dutch War, the VOC had to resort to buying or leasing ships, but the speed of these ships does not differ from that of the company-built ships.

With the collapse of the VOC in 1800, however, Dutch built merchant ships rapidly gain in speed until they match the speed of British merchant ship sometime between 1820 and 1848. From 1745 to 1850, they gain 43 nm (80 km) in average day's run, an increase of 53 percent, and 59 nm (108 km) in best day's run, a gain of 30 percent. Since all of this gain comes after 1800, this is a much faster gain than the privately built EIC ships.

In conclusion, ship speed undoubtedly improves over the period from 1730 to 1850. The establishments and standardization of scantlings by navies and companies during that time does limit the speed of those ships, however. In the case of the VOC, where extremely tight controls on ship design were in place, this results in no gain in ship speed at all. In the case of the British navy, where contracts were specific but not set in stone, less gain in ship speed—and especially ship speed beyond that expected by the gain in length—is seen than among privately built ships. However, the gain in length and tonnage are themselves significant, and enough to improve both average and maximum speeds obtained by ships. When not constrained by standardization within institutions, ships gain in speed even when length does not increase. Improvements in ship design and outfitting for this period are therefore evident beyond the increase in ship size.

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